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AIR FORCE SYSTEMS COMMAND RESEARCH PLANNING GUIDE [RESEARCH OBJECTIVES]

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LIFE SCIENCES
MATERIALS
GEOPHYSICS
AEROSPACE VEHICLES
PROPULSION AND POWER
WEAPONRY
ELECTRONICS
COMPUTATIONAL SCIENCES
PROJECT FORECAST II

DCS/SCIENCE AND TECHNOLOGY
HQ AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

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AIR FORCE SYSTEMS COMMAND

RESEARCH PLANNING GUIDE

1 FEBRUARY 1987



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DCS for Science and Technology

HQ Air Force Systems Command

Andrews Air Force Base DC 20334

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INTRODUCTION

The Air Force Systems Command (AFSC) Research Planning Guide provides a basis for the annual Air Force Plan for Defense Research Science (Program Element 61102F). The purpose of the Guide is to direct the attention of the scientific community to the technology interests of the Air Force, to provide a prospectus of research objectives to which the scientific community can respond, and to document the relevancy of fundamental investigations to the Air Force mission.

The research objectives described here represent the combined counsel of technical directors and program managers in Air Force research and development laboratories. These objectives enunciate scientific opportunities which, when exploited, will provide fundamental knowledge required to develop alternatives in solving technological problems which mitigate the superiority of Air Force systems. The objectives are grouped into eight technical areas: life sciences, materials, geophysics, aerospace vehicles, propulsion and power, weaponry, electronics, and computational sciences. These areas relate directly to Air Force mission areas and involve such scientific disciplines as physics, chemistry, biology, psychology, mathematics, and engineering.

The last chapter of this Planning Guide describes selected Project Forecast II technology initiatives. Project Forecast II was a comprehensive study to identify new technologies with exceptional promise for improving the Air Force's warfighting capabilities. The Project was directed by the Commander of AFSC, General Lawrence A. Skantze, and was supported by a team of 175 military and civilian experts drawn from within AFSC and the operational commands. From the ideas generated by the AF laboratories, industry, academia, and technology panels 39 initiatives were identified for funding within the Science and Technology program budget. Of these, the following are considered to be opportunities for research investment and are included in this document:

- PT-01 - High Energy Density Propellants
- PT-05 - Space Power
- PT-10 - Wafer Level Union of Devices
- PT-11 - Photonics
- PT-12 - Full Spectrum, Ultra-Resolution Sensors
- PT-14 - Survivable Communications Network
- PT-15 - Adaptive Control of Ultra-Large Arrays
- PT-20 - Ultra-Structured Materials
- PT-21 - Cooling of Hot Structures
- PT-24 - Hypersonic Aerothermodynamics
- PT-26 - Brilliant Guidance
- PT-36 - Knowledge-Based Systems
- PT-40 - Virtual Man-Machine Interaction
- PT-41 - Distributed Information Processing

Additional information on Project Forecast II can be obtained from HQ AFSC/DLXP, Andrews AFB DC 20334.

As previously stated, the principal role of the Planning Guide is to stimulate and focus the thinking of the scientific community. The intent is to encourage response in the form of proposals which can be included in the Air Force research program. The responsibility for formulating and managing that program is vested in the Air Force Office of Scientific Research (AFOSR), Bolling AFB DC 20332. AFOSR accomplishes that function through contracts and grants to academic, industrial, and not-for-profit research organizations. In addition, AFOSR manages inhouse research in the AFSC research and development laboratories:

Air Force Human Resources Laboratory (AFHRL), Brooks AFB TX 78235

USAF School of Aerospace Medicine (USAFSAM), Brooks AFB TX 78235

Harry G. Armstrong Aerospace Medical Research Laboratory (AAMRL), Wright-Patterson AFB OH 45433

Frank J. Seiler Research Laboratory (FJSRL), Air Force Academy CO 80840

Air Force Armament Test Laboratory (AFATL), Eglin AFB FL 32542

Air Force Geophysics Laboratory (AFGL), Hanscom AFB MA 01731

Air Force Astronautical Laboratory (AFAL), Edwards AFB CA 93523

Air Force Weapons Laboratory (AFWL), Kirtland AFB NM 87117

Air Force Wright Aeronautical Laboratories (AFWAL): Aero Propulsion Laboratory, Avionics Laboratory, Flight Dynamics Laboratory, Materials Laboratory, Wright-Patterson AFB OH 45433

Rome Air Development Center (RADC), Griffiss AFB NY 13441

Engineering and Services Laboratory (AFESC), Tyndall AFB FL 32403

Prospective contractors may obtain pre-proposal technical information from the points of contact listed at the end of each subarea, however, these contacts are not permitted to assist in the formulation or submission of proposals. Information documents for proposers, including the Broad Agency Announcement entitled Research Interests, can be obtained from AFOSR/XOT, Bolling AFB DC 20332.

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LIFE SCIENCES

TECHNICAL AREA

LIFE SCIENCES

INTRODUCTION

The life sciences research program is directed toward enhancing the performance of Air Force personnel, protecting personnel from hazards, and improving human-machine interactions. People are an indispensable part of every Air Force system; their effectiveness determines the success or failure of Air Force missions. Personnel-related costs now comprise the largest category of expense in the DOD budget. We require effective techniques to select individuals on the basis of their abilities and train them to perform their jobs well. Modern equipment systems place severe demands on human capabilities. We urgently need to understand the nature of sensory and cognitive information processing in order to train individuals effectively and design equipment for optimal use by humans. Basic biological processes must be understood in order to protect personnel from physical stresses such as those involved in high-speed aircraft maneuvers, from toxic chemicals and radiation exposure encountered in Air Force operations.

See also Project Forecast II initiative PT-40 Virtual Man-Machine Interaction (section 9.1.13) which seeks to exploit the natural capabilities of the human in order to minimize cognitive demand and create an efficient human-machine communications medium.

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SUBAREA NUMBER 1.1

TECHNICAL AREA - Life Sciences

SUBAREA TITLE - Manpower Selection
and Training

SCOPE

These objectives address the requirement for basic research to provide the theoretical framework for development of more effective predictive, instructional and assessment techniques to insure the best use of available Air Force manpower. These requirements for research are relevant to the development of technological capabilities and applications in (1) manpower and force management, (2) air combat tactics and training, and (3) weapon system logistics and maintenance.

1.1.1 Skill Acquisition

To provide the best selection and training procedures for Air Force weapon systems operators, we must understand the underlying parameters of human learning. Basic research is needed to define the meaning of baseline performance levels, and to determine the internal and external variables which influence both the differences in rate and the limits of skill acquisition and skill retention across individuals. Such variables might include structure of material to be learned, as well as the role of short- and long-term memory, expectations, set, and other motivational issues.

1.1.2 Crew Training

To insure the most effective operation of modern weapon systems, it is often necessary for Air Force personnel to perform complex tasks as highly coordinated, but flexible teams. Basic research is needed to understand the dynamics of decision making and performance within groups varying in dimensions such as size, cohesiveness, and responsibility levels.

1.1.3 Performance Assessment

Before effective selection and training procedures (models) can be developed, we must be certain that the methods used to measure aspects of performance are valid and reliable. Basic research is required to develop and test such measures.

POINTS OF CONTACT

AFOSR/NL
AV 297-5021
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SCOPE

Equipment designers can no longer rely on the great flexibility of human operators to adapt to peculiarities of equipment systems and obtain maximum performance. Modern equipment systems and current combat environments place enormous demands on the human operator's capacity to rapidly process a wide range of data, analyze that data accurately and respond appropriately. Optimum performance requires close matching of equipment design to human sensory and cognitive information processing. To provide this match, equipment designers and human factors engineers require the knowledge generated by basic research on human sensory and cognitive processes. This basic knowledge will also contribute to more sophisticated approaches to artificial intelligence.

1.2.1 Sensory Processes

Research is needed to discover the capabilities and limitations of the human visual and auditory systems. This research should include the mechanisms for extracting and encoding spatial and temporal information, perception of patterns, and the effects of higher-order processes on perception. It should also include the auditory mechanisms for extracting features from complex sounds.

1.2.2 Cognitive Processes

Research is needed on the representation and utilization of perceptual knowledge, attention, memory representation, reasoning and judgment. Both behavioral and physiological studies of the mechanisms used in these cognitive processes are required.

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SUBAREA NUMBER 1.3

TECHNICAL AREA - Life Sciences

SUBAREA TITLE - Aerospace Physiology

SCOPE

Human performance is the outcome of the activity of the nervous system. Elucidating neural mechanisms provides ways to understand and enhance human performance. For example, human performance is often degraded by fatigue, jet-lag, disruption of sleep and stress. Discovering the neural processes involved in these conditions will reveal ways to prevent these undesired effects.

Living organisms learn from experience and form memories through changes in synaptic transmission between neurons. Discovering the nature of those changes would shed light on the nature of human capabilities and would also lead to ways to design computers capable of learning from experience.

High performance aircraft stress human physiological functions severely, especially through high g forces and vibration. These stresses cause both immediate problems, such as loss of consciousness, and delayed problems, such as interference with normal maintenance of bone structure and function.

1.3.1 Neural Regulation

Research is needed to discover the basic mechanism through which the responsiveness of neurons to their synaptic inputs is regulated. This research should include the role of neural regulation in determining the state of responsiveness of the intact organism, for example, the neurobiology of the biological clocks that set our sleep-wakefulness cycles.

1.3.2 Adaptive Networks

Research is needed to discover the changes in neural circuits that occur when an organism learns and forms short and long-term memories. Research is also needed to model computer architectures with adaptive components on the features found in neural circuits.

1.3.3 Bone Structure and Function

Research is needed to discover the ways in which vibration, loading, and the absence of loading (as in micro-gravity) affect the normal processes by which bone structure is continually replenished and bone mass regulated.

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SCOPE

Air Force operations involve physical and chemical agents that could be harmful to Air Force personnel, the surrounding populace and the environment. National policy requires that all operations be assessed as to impact on humans and the environment, and controlled to the extent necessary to prevent degradation to health and the environment. Data and methods are needed to assess, measure and control Air Force-generated chemical and physical agents to the extent necessary to meet national standards while maintaining operational flexibility. An understanding of the fundamental interactions of these agents with biological systems and their actual mechanisms of action is required to provide effective means of protecting humans and the environment from their associated hazards. In addition, Air Force personnel may be exposed to chemical warfare agents used by an adversary. The USAF has an obvious interest in acquiring the means to offset the effects of such chemical agents. Fundamental information on the mechanisms of the biological action of chemical agents and their interaction with material is required in order to devise novel methods for the protection of Air Force personnel. With the increase in manned space flight in the Shuttle era, increased emphasis needs to be placed on the effect of high energy radiation in space on Air Force personnel. The space environment may also have an adverse effect on life-support systems, which must be considered in system design and operational planning.

1.4.1 Toxicology

A prime objective in this area is to find early biochemical and/or morphological indicators of latent toxic response in order to decrease the time and cost required for current chronic effects studies. A second major objective is to clarify the actual toxic action mechanisms of Air Force chemicals at the cellular and molecular level. In addition to genotoxic effects, studies are required to determine mechanisms of action on other systems, with emphasis on immune and nervous system responses. A third objective is to understand biotransformation mechanisms in the hopes of increasing the body's capability of handling toxic insults.

1.4.2 Electromagnetic Radiation Bioeffects

The main objective is to determine the effects of the interaction of electromagnetic energy with biological tissue. The effects of long-term, low-level exposures to both pulsed and continuous wave radiation must be determined. The fundamental mechanisms of action of radio frequency radiation on living tissue must be clarified at the cellular and molecular level.

1.4.3 Chemical Environmental Fate and Effects

The objective of this area is to determine the environmental fate and consequent biological effects of Air Force chemical compounds which might inadvertently get into natural systems. Major emphasis should be on various ecological end points to include community stability and population dynamics with minor emphasis at the organism level. Studies should also include the metabolites and degradation products of the chemical compounds.

1.4.4 Space Radiation Bioeffects

The objective of this research is to better determine the detrimental biological effects of space radiation on human tissue. There needs to be a better specification of the severity of the radiation hazards and a clearer definition of the exposure limits. Studies should focus on radiation exposure limits unique to the space environment.

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MATERIALS

TECHNICAL AREA

MATERIALS TECHNICAL AREA

INTRODUCTION

The Air Force research program in materials is guided by the recognition that future advances in low cost, reliable, long life, high performance weapons systems are dependent upon the availability and effective utilization of superior materials. Many of today's advanced systems impose performance and capability requirements for structural, propulsion, thermal protection, and support materials that are barely within the current state-of-the-art. The requirements of advanced generations of weapons systems will not be met without significant advances in materials technology and the kind of far-sighted materials research programs which will make those advances possible.

Progress in materials science is best attained through multidisciplinary efforts, combining the methods of physics, chemistry, mathematics, metallurgy, mechanics, electronics, and computer science. Research plans for materials programs tend normally to be discipline oriented and to be described in terms of the fundamental physical, chemical, and mechanical phenomena underlying the useful properties of metals, ceramics, composites, polymers, organics, and electromagnetic materials and methods for synthesizing as necessary these materials into useful components. New scientific concepts and improved general understanding in these areas will afford many future advances in materials technology. In addition, support may be provided for requirements not yet recognized or articulated. In this document, however, emphasis has been placed on the establishment of clear relationships between materials research objectives and goals and presently documented and anticipated Air Force technology and system needs.

To do this, the materials research area has been divided into six Subareas, as follows:

Subarea 2.1, Structural Materials, contains research objectives related to materials which will be used primarily in applications stressing their load bearing ability. These applications, for example, are ones in which generally the understanding of factors influencing strength, toughness, stress corrosion, stiffness, and resistance to creep and fatigue are essential.

Subarea 2.2, Environment Resistant Materials, contains research objectives related to materials which will be used primarily in applications where aerospace systems or their components must be protected from either natural or enemy induced hostile environments.

Subarea 2.3, Electromagnetic Materials, contains research objectives related to materials which can generate, detect, process, control, or otherwise usefully employ electromagnetic energy for Air Force needs. Electromagnetic material applications and therefore areas requiring research include more sensitive infrared detectors, higher speed and higher power electronic devices, active and passive protection from high flux laser and ionizing radiation, and electro-optical and acousto-optical devices for communications and new electronic systems.

Subarea 2.4, Fluid, Lubricant, and Containment Materials, contains research objectives related to materials which serve a wide variety of critical functions in advanced aircraft and aerospace systems. Typical applications of these materials include hydraulic actuation media, coolants, engine lubricants, fuel tank seals, and the many similar requirements which are so vital to the AF mission.

Subarea 2.5, Nondestructive Evaluation, contains research objectives related to the study of physical, chemical, or mechanical phenomena which could underlie new or significantly improved inspection and evaluation techniques for aerospace structures, power plants, and electronic instrumentation. Equally significant to this interdisciplinary technology are studies of such diverse areas as defect-interrogating energy relationships, new sensor/detector development and signal processing methodologies, to name a few.

Subarea 2.6, Manufacturing Research, contains research objectives related to processing science studies aimed at new or improved methods for the fabrication of metals, ceramics, organics, composites, and electromagnetic materials or devices and to the development of a broad, interdisciplinary science base required for intelligent manufacturing task automation.

See also Project Forecast II initiative PT-20 Ultrastructured Materials (section 9.1.8) which seeks major research efforts in ultra-structured materials definition, required processing techniques, and theoretical/experimental modeling.

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- 2.6.1 Processing Science
- 2.6.2 Manufacturing Science

SCOPE

Structural materials in use today are operating at or near their capacity with regard to stress, temperature, and environment. Yet, it is necessary to prolong use of current systems, and to envision new ones which will demand lighter weight structures of extreme reliability and resistance to corrosive attack or sudden failures. Progress toward development of a rational basis for creating or improving material systems (such as alloys, polymers, glasses, ceramics, and composites) can be attained through understanding of the principles that govern properties and behavior as a function of molecular or microstructural features, composition, and processing history. Failures such as creep, fatigue, and fracture are in most cases intimately related to microstructures of materials. Understanding of these processes and the governing mechanisms must ultimately be integrated with appropriate macroscopic description by use of general constitutive equations of mechanics.

The long-range research goals in materials extend beyond the problems of new materials development. It is anticipated that considerable progress can be achieved in structural reliability and integrity as a result of basic studies which attempt a combined materials/mechanics viewpoint. However, oversimplification of highly interactive phenomena, such as those between the load and environment, and empirical correlation without reference to governing principles could lead to erroneous conclusions. Instead, emphasis should be placed on sound modeling of coupled phenomena and mechanisms. Establishment of relevant properties and associated test procedures will lead to predictability of material behavior under real service environments, from which the level of durability demanded by current and future systems can be rationally achieved.

2.1.1 Structural Materials Design

A rational basis for the development of alloys, nonmetallic materials, ceramics, and composites is required. A methodology can then be developed to provide comprehensive and systematic consideration of softening, strengthening, and hardening mechanisms, generation and propagation of defects, role of microstructures, effects of boundaries and interfaces, phase transformations and stability, thermodynamics of alloying, and the relationship of microscopic phenomena to macroscopic properties. The objective of this research is to understand and explain the mechanical properties of materials and their fundamental relationship to microstructural and compositional variations.

This methodology is needed to obtain full use of new or improved materials without the expensive and time-consuming trial-and-error approach which characterizes current state-of-the-art. In order to meet the need for the present limitation, understanding of the factors that control mechanical properties and behavior is required. Specific needs include: (1) development of reliable high strength nickel base alloys, aluminum and titanium alloys

alloys; aluminum and titanium alloys with high modulus/low density ratios; aluminum and titanium alloys with increased temperature capabilities; aluminum alloys with improved fracture toughness for engine applications; weldable high strength aluminum alloys for aircraft structural applications; metal matrix composites with high tensile and fatigue strength and improved modulus/density ratios; organic matrix composites with improved performance properties in higher temperature environments; carbon/carbon composites with improved thermo-oxidative stabilities and mechanical properties; structural adhesives with improved resistance to thermo-mechanical and environmental effects; and alloys specifically formulated for powder metallurgical fabrication of high structural efficiency and high integrity components. The need for analytical modeling is acute in the field of organic matrix composites, carbon/carbon composites, and bonded joints in structures.

2.1.2 New Polymeric Materials

Approaches are needed to the synthesis and characterization (See 2.1.3) of environmentally stable polymeric materials specifically tailored in molecular structure for new, higher performance, processable, matrix resins, adhesive thermoplastics, and other structural materials or prepolymers. Included are (a) high molecular weight, processable polymers exhibiting high thermal stability which by virtue of chemical additions, cycloadditions, or rearrangements can be cured to high strength thermoplastic structural materials, (b) polymers containing high degrees of chain rigidity which can be ordered (and/or oriented) and processed to high strength materials such as spun fibers, extruded film, and molecular composites containing rigid rod-like polymers, and (c) reactive oligomers capable of being converted to environmentally resistant, high molecular weight, high glass transition temperature materials by controlled chemical addition reactions, and/or molecular rearrangements for structural composite matrices. Low cost synthesis routes must be explored as well as high performance end products. New approaches to low energy chemistry for curing reactions need to be investigated. This also includes research to provide improved new polymer curing reactions and approaches to the synthesis of specifically structure chemical intermediates, multifunctional monomers, and cross-linking agents required to produce the above structural polymeric materials. Knowledge of precursor monomeric, oligomeric, or polymeric materials are needed for subsequent fabrication into higher performance carbon/carbon composite structures.

2.1.3 Polymer Structure-Property Relationships

Extensive experimental work is needed from polymer characterization to confirm structure-property correlations, physical and chemical property correlations. This work must be applied to the synthesis and processing of monomers, prepolymers, polymers, matrix resin composites and molecular composites and to the resultant changes in properties, namely with respect to thermal stability, processability, mechanical behavior, and costs to fabricate polymer structural components. Fundamental structure-property correlations are needed to interrelate physical and mechanical properties with molecular structure and composition. The correlation of these with chemical structure and morphology. The elucidation and application of fundamental structure-property correlations is essential for the

development of synthesis and processing chemistry (See 2.1.2) needed to generate new resin systems. For example, new polymers are needed for resins which will exhibit better than state-of-the-art elevated temperature mechanical properties in the presence of moisture, but without significant sacrifices in either processability or costs compared to current epoxy resins. New rigid rod molecule polymers specifically varied in chemical composition to influence the morphology of intermolecular packing and interactions are needed to improve molecular composite processing and to understand and achieve improved compressive strength in the bulk, basic knowledge on surface interactions is needed. More fundamental knowledge is needed to understand the morphology of polymers, how it interrelates and can give desired combinations of processing rheology, mechanical properties, surface energetics and overall engineering behavior. Correlations with variations in approaches and methodology or processing are needed. Processing science investigation to obtain higher degrees of toughness and compressive strength are critically important areas needing greater depths of understanding. A technical basis must be provided for the reliable prediction of use properties from the polymer structure and properties of candidate materials for advanced fiber reinforced composites, adhesives, and the newly emerging technology of molecular composites.

2.1.4 Metals and Ceramics

New approaches leading to higher performance of nickel, aluminum, and titanium alloys and ceramics are required to provide future Air Force weapon systems components with structural capacity capable of reliable sustained operation.

With the advent of powder metallurgy/rapid solidification technology (PM/RST) this area has become extremely vibrant with many technical advances. Unfortunately, the science base to support these developments is trailing the technical advances and could seriously block full exploitation.

Aluminum and Titanium Alloys - Three generic families of PM/RST alloys are being investigated for both alloy systems: (a) corrosion resistant/high strength, (b) reduced density/increased modulus, and (c) enhanced temperature capability alloys. Fundamental understanding of the boundaries of solubility, stability of metastable phases, role of superheating and undercooling, nucleation sites, influence of oxide skin and kinetics of second phase growth (particularly during processing thermal excursions) are required. An understanding of the basic mechanisms operating during the processing of these alloys is necessary, particularly that governing the distribution of oxides and influence on mechanical behavior. Because of the large surface area/volume ratio characteristic of powders, an understanding of the surface behavior is essential. This should include nature and location of oxides, and should be extended to studies of methods to modify the oxide to allow for easier compaction/high integrity components. Process modeling of the deformation behavior of less than 100 percent dense compacts is required together with correlations between laboratory scale processing and full scale production fabrication.

Metal Matrix Composites - Here the mechanical behavior of monolithic metal alloys are enhanced by combining them with high strength/high modulus fibers such as SiC, B, and graphite, which can be either continuous or discontinuous (staple fibers). However, while some properties such as

modulus are readily improved other properties such as tensile and fatigue strength and fracture toughness do not reach predicted values. Basic research is needed to define failure mechanisms as a function of matrix material and filament type, to allow work to be directed towards improving these properties. This should include a detailed study of the reaction zone between matrix and the fiber, and should include complex multidirectional spectrum loading as well as more simple unidirectional tensile loading.

Nickel Alloys - Basic research is required to identify thermodynamically stable oxidation-resistant turbine engine blade and vane materials processing high melting points and significantly improved stress rupture and fatigue properties. An improved basic understanding of rapidly solidified powder metallurgy is especially important in view of its potential for producing alloys with superior properties.

Titanium and Iron Aluminides - Basic research to identify approaches leading to the formation of new aluminide systems capable of sustained operation at temperatures up to 1600°F are needed for advanced propulsion system critical components such as blades and disks.

Ceramics and Ceramic Composites - Basic research to identify new families of ceramic materials capable of economical consolidation and possessing improved creep, thermal stress, and static fatigue resistance is needed to extend the limits of future generation high temperature turbine engine components. An improved understanding of the design, fabrication, and properties of ceramic matrix composites is especially important.

Carbon/Carbon Composites - Improved understanding of the design, fabrication, and properties of high strength carbon/carbon composites warrants increased attention to assess the potential of and/or lead the way into a new generation of development of these materials.

2.1.5 Plastic Deformation

The design requirements for aerospace aircraft and propulsion structures are forcing the increased use of high toughness materials. Current analysis techniques, based upon linear elastic fracture mechanics, are limited in their ability to predict behavior of materials that undergo large amounts of plastic deformation prior to fracture. New concepts for the derivation of fundamental metallurgical factors which govern crack initiation and propagation phenomena in structural materials that experience plastic flow prior to failure is needed to account for thermally and mechanically activated plastic deformation. Problem areas include the development of failure and propagation criteria which extend beyond the basic assumptions of modified linear elastic theories. Improved understanding of the role of metallurgical structure, the limiting stress/strain parameters, and the effects of temperature and environment are particularly important.

2.1.6 Dynamic Loading

A fundamental understanding of the response of aircraft and propulsion materials to high rates of applied mechanical and thermal impulse is needed. Problem areas include failure mechanisms and resulting strength degradation due to shock, foreign body impact, and high density radiation loading events. Monolithic and composite structural materials exposed to intensive

thermal or mechanical loading during micro and nano second intervals can directly affect the safety, life, and survivability of aircraft and propulsion structures. Soft and hard foreign body impacts experienced by turbine engine blading, and thermal impulses generated by laser devices are representative of high rate loading events requiring definition in order to generate appropriate design criteria.

2.1.7 Quasi-Brittle Fracture

Mechanisms of subcritical crack growth are affected by state of stress, environment, microstructure (including size and distribution of precipitates or inclusions), and interface interactions. Both microscopic approaches (such as dislocation theory) and macroscopic approaches (such as fracture mechanics and failure criteria) are needed.

Events which lead to failure without warning may be alleviated if the events can be systematically modeled and simulated in the laboratory. Relevant information could be obtained from studies of stable and unstable crack growth under variable tensile load with geometric and material discontinuities, and initiation of defects in materials due to processing, fabrication, and use. Design criteria for quasi-brittle materials, including methods for interrogation and monitoring the state of health of the materials, and early warning of impending failures, are required for predictability and reliability.

2.1.8 Fatigue

A detailed understanding of the mechanisms of crack initiation and propagation under variable and repeated stressing is needed. Problem areas include slip band movement, residual stress, loading sequence, environmental influence, cumulative damage, stress concentrations, spectral loadings, and associated interactive effects of plastic flow, creep, oxidation, and corrosion.

Fatigue properties are directly related to the longevity and safety of structures. A more fundamental understanding of fatigue mechanisms, crack growth mechanisms, and plastic zones at a crack tip will lead to superior materials and more reliable design for specific applications such as: aluminum airframe materials with improved notched fatigue properties; superalloys, dispersion strengthened materials, monocrystals, and titanium alloys for turbine engine components with improved high-temperature low-cycle fatigue properties; and metal matrix composites for both engine and airframe usage. This should include a detailed characterization of the mechanism of fatigue initiation in metallic alloys particularly those fabricated by powder metallurgy techniques. Definition of the role played by inclusions and oxide films should allow enhancement of mechanical properties particularly those which are closely related to initiation such as fatigue, ductility, and fracture toughness. Predictable cumulative damage under spectral loading is essential for design to a required reliability. Analysis and verification of fatigue and residual strength interaction may provide the guideline necessary for better design criteria and life-prediction. It may then be possible to forecast fatigue failures through accelerated tests, to validate structures through proof tests, and to monitor the safety of structures through nondestructive tests.

2.1.9 Creep, Stress Rupture, and LCF Interactions

Description and explanation of flow and fracture at elevated temperatures can be achieved through fundamental investigations of temperature, environments, strain history, and interactive low cycle fatigue dwell time. Identification and quantification of failure mechanisms can lead to an understanding of mechanical properties related to life of materials.

Structural integrity and reliability at sustained elevated temperatures and hostile gaseous environments are vital requirements for turbine engine components and other Air Force applications. A comprehensive understanding of failure mechanisms operative under biaxial and triaxial loading conditions at high temperatures are needed to produce a direct improvement in operational life, systems operating efficiency, and lower net life cycle cost.

2.1.10 Corrosion and Stress Corrosion

Predictability of the effects of corrosion on the loadbearing capability of structures requires fundamental knowledge of chemical, electro-chemical, mechanical, and metallurgical influences, and their interaction. Durability, which has direct impact on safety and life cycle cost of Air Force systems, is severely limited by hostile environments. Because the degradation of structural integrity by corrosion is a highly coupled phenomenon, sophisticated analytic and experimental skills from diversified fields will be needed to address the problem.

2.1.11 Failure Mechanisms of Filamentary Composites

Failure of composites can be a combination of fiber, matrix and interface failures, and interlaminar delamination. These failures on the local scale must be related to gross mechanical properties like stiffness, strength, and toughness.

Structural integrity of filamentary composites is a key issue in the use of composites in Air Force vehicles. Initiation and growth of defects due to local failures must be related to life and strength degradation through some analytic model consistent with established principles of mechanics.

2.1.12 Life Predictions for Materials

Cumulative damage models for metals and composites due to time-varying loading and environments are required as a basic building block for life predictions. This model should be derived for laboratory-size specimens with and without stress concentrations. Effects of mean stress, positive and negative stress ratios, combined stresses, overloads, rate and frequency of loading, hold time, load sequencing, and temperature need to be investigated. Materials can then be designed to a required reliability. A life prediction methodology can determine current residual strength and life expectancy. Such methodology can lead to accelerated testing, design criteria to avoid damaging stresses during life of structures, and means to guarantee safe life for a given usage.

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SCOPE

This subarea is primarily directed toward materials which are specifically designed, modified, or used for their environmentally resistant qualities. Polymers, metals, ceramics, and composites are used to enhance the survivability of the crew and aerospace systems and to provide reliable, durable, cost effective, easily maintained components to such systems. Research includes work on heat shield, nose cap, leading edge, and hot surface panel materials which accomplish their protective function by ablation, re-radiation, insulation, transpiration cooling or heat sink concepts; propulsion system materials which are exposed to high temperature chemically corrosive and oxidative environments; coatings which must be compatible with the substrate material while protecting it from the various hostile environments; and special function materials including laser device materials, transparent and personnel armor, and rain erosion protective layers. The mechanisms responsible for materials degradation in hostile environments must be studied to provide a rational basis for developing environmentally resistant materials and to be able to predict materials response and life time in service. Severe conditions of temperature, mechanical erosion, oxidation, chemical corrosion, laser interactions, conventional and nuclear weapons effects, and their combinations are included.

2.2.1 High Temperature Environment Resistance

Determine the mechanisms of interaction between structural or thermal protection materials and the high temperature hostile environments in which they must operate. Determine techniques for achieving improved compositions and microstructures for materials designed to withstand these conditions. Relate starting materials, processing methods, phase stability and fabrication methods to material properties to provide a base for material improvement. Obtain fundamental thermophysical and thermochemical property data on these materials. Determine the factors that control synthesis adherence, interactions with the substrate, and thermodynamic stability of coatings designed to protect high temperature materials from reactive atmospheres.

2.2.2 Ambient and Low Temperature Environment Resistance

Identify improved composition and microstructure for corrosion resistant metal, ceramic, organic, and composite structures. Relate phase equilibria, induced non-equilibrium structures, and segregation of impurities to the desired properties of the materials. Determine mechanisms of stress and corrosion interactions, including stress corrosion, hydrogen embrittlement, and corrosion fatigue. Establish a fundamental basis for evaluating corrosion prevention and control measures and develop predictive techniques for forecasting corrosion damage and maintenance scheduling for aerospace systems and equipment. Obtain fundamental data pertinent to the material-environment interaction, such as surface diffusion coefficients, energy

states, and effects of composition and structure. Determine the characteristics of polymer structures and films that inhibit degradation due to weathering and provide corrosion protection through reduced permeability. Determine the factors which affect the film formation properties and solubility characteristics of coatings and the mechanisms of corrosion inhibition. Establish a basis for the development of an accelerated testing technique whereby laboratory tests can be used to predict the in-service behavior of materials.

2.2.3 Radiation Resistant Materials

Aerospace systems must be protected from solar, laser, and nuclear radiation. Determine fundamental mechanisms of interaction of IR, UV, X-ray, electron, and other forms of radiation with aerospace materials and coatings. Determine mechanisms of material degradation. Investigate phenomena which could be used as the basis for the selective and controlled reflection, transmission, or absorption of radiation.

2.2.4 Thermochemical Environment Resistance

The thermochemical behavior of polymers, refractory compounds, composites (including carbon/carbon composites), and other aerospace materials should be determined and related to their effectiveness as thermal protection materials. Determine the recession rates, reaction products, and reaction mechanisms for new ablative materials. Obtain a fundamental understanding of the processing of carbon/carbon composites to generate new and improved materials concepts, simplify processing, reduce processing time and costs, enhance composite properties, and obtain uniform microstructure composites for repeatable performance. The carbon/carbon process should be analytically modeled in terms of constituent materials and processing variables. Microstructural features should be related to properties and performance. Defect/property relationships should be formulated. A basis for the development of high temperature oxidation protection coatings for carbon/carbon should be established.

Establish fundamental kinetic response data, including sublimation parameters and heterogeneous effects due to macro/microstructures of polymeric, composite, and refractory materials subjected to a high temperature erosive environment. Define the mechanisms of ablation and physical change, including scale formation and adherence, due to thermochemical reactions of materials with high temperature corrosive environments and establish the mechanics of failure to allow generation of a damage prediction model.

2.2.5 Erosion and Ballistic Impact Resistance

Determine the mechanisms of material degradation and failure under mechanical erosion and ballistic impact conditions. Develop models for the prediction of the useful lifetimes of both structural materials and protective coatings. Determine the influence of compositional, microstructural, and processing parameters on the erosion and ballistic impact damage of aerospace materials. Establish the compositional and microstructural features of improved erosion resistant and mechanical damping materials suitable for use as protective coatings.

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SCOPE

This subarea encompasses a broad spectrum of research objectives that are related to the synthesis, preparation, characterization, and analysis of electromagnetic materials. These efforts normally include detailed understanding and control of material purification, film and crystal growth, defect structure, selective and controlled doping, and related processes and phenomena. The materials are generally in the condensed state, either crystalline or amorphous in form. In view of their potential impact on new and improved electronic and electro-optic components and aerospace systems, improved understanding of the basic mechanisms responsible for their optical, acoustic, magnetic, dielectric, semiconducting, superconducting, radiation tolerance, and insulating properties is needed as a foundation for the evolution of novel and advanced device concepts. These devices utilizing the special properties and characteristics of advanced electromagnetic materials could have a profound influence on the Air Force's ability to carry out its reconnaissance and surveillance; navigation and guidance; command, control, communication and intelligence; and electronic warfare responsibilities and functions. Subareas with related objectives can be found under Technical Area 7, Electronics.

2.3.1 Synthesis, Growth, and Preparation

Explore experimental methods and techniques for the synthesis and growth of suitable electromagnetic materials in monocrystalline, polycrystalline, or noncrystalline forms. Prepare and treat desired configurations and geometric shapes such as bulk materials, thin films, fibers and layers in heterogenous and homogenous structures. Study processes which can provide electromagnetic materials with predictable and reproducible special properties and characteristics.

2.3.2 Characterization of Properties and Constituents

Develop new and improved methods for the analysis and identification of chemical constituents, defect structure, impurity content, band structure, compositional phase, crystallographic or amorphous structure, and the structural integrity and morphology of electromagnetic materials. Apply materials sciences for the improved understanding and control of the special optical, acoustic magnetic, and electronic properties and performance.

2.3.3 New Methods and Techniques

Develop innovative concepts and methodologies for the design synthesis, growth, and preparation of suitably selected electromagnetic materials with desired properties. Evolve new and advanced methods and techniques which can better predict, resolve, and determine the extrinsic and intrinsic properties and performance of electromagnetic materials. Research should include computer modeling and designed semiconductor structures (e.g. superlattices).

2.3.4 Optical Materials

Investigate the electronic structure and optical properties of selected electromagnetic materials in bulk, thin film, fiber, single crystal, or glassy state forms and configurations. Investigate the mechanisms of picosecond effects resulting from laser interactions with optical materials. Study linear and nonlinear optical effects in very narrow bandgap semiconductors. Explore and discover new phenomena and effects in solid state semiconducting materials which may generate new and useful sources of radiation and more sensitive detectors of radiation, especially in the far and infrared and submillimeter spectral regions.

2.3.5 Microwave Materials

Study the potentials of compound semiconductors and heterojunction structures for low power microwave detectors, sources, resonators, filters, amplifiers, and signal processors. Grow and prepare suitable crystals and fabricate appropriate configurations of selected semiconducting compounds. Investigate and correlate their electronic, acoustic, and magnetic properties with respect to potential solid state microwave components. Investigate the mechanisms of activation and degradation of high power microwave tube cathodes and other life-limiting tube materials.

2.3.6 Semiconducting Materials

Investigate and analyze semiconducting materials for a wide variety of microwave, electro-optic, high speed data and signal processing, and related quantum electronic device concepts. Research should seek to synthesize new and improved materials to prepare, process, and treat the materials that are grown, to seek optimal properties for potential applications at the nanometer level (ultra small electronic research), to investigate interaction effects between materials at the interfaces of microelectronic structures, and to study transport phenomena and develop applicable theories and models for the behavior of materials in microelectronic configurations. This should include designed materials such as superlattices for electronic and optical applications.

2.3.7 Superconducting Materials

New approaches to higher power conditioning, to remote sensing and detection of electromagnetic radiation, and to high speed, high density memories are much dependent upon new and improved superconducting materials. Research objectives should include synthesis and characterization of superconducting materials possessing higher critical transition temperatures, higher upper critical magnetic fields and higher current carrying capabilities. Enhancement of these critical superconducting parameters requires combining the interdisciplinary methods and approaches of metallurgy, crystal chemistry, and solid state physics. The relationships of structural properties to critical superconducting parameters should be studied and predictive principles for custom-making optimal materials suitable for superconducting micro and macrodevices should be determined.

2.3.8 Dielectric Materials

Investigate the structure, properties, performance and degradation of new insulating materials for integrated microcircuitry and electronic signal/data processing.

2.3.9 Interfaces and Surfaces

Study, on an atomic scale, the physics and chemistry of electromagnetic materials at or below their surfaces and interfaces. Seek new insights on interaction effects, degradation, catalysis, surface layer effects, epitaxial growth, atomic clustering, bonding mechanisms, and related phenomena. Seek correlations of surface and interface chemistry, crystallography, and other physical characteristics with electrical properties of a variety of electronic materials.

2.3.10 Radiation Hardened Materials

Gain an understanding of the basic physical and chemical mechanisms underlying the degradation of electromagnetic materials subjected to intense coherent or incoherent radiation over all regions of the electromagnetic spectrum. Develop techniques for hardening materials, and for the selection of materials which can withstand or resist the deleterious effects of electromagnetic irradiation. Included are nuclear, X-ray, ultraviolet, infrared and microwave radiant energy in pulses or continuous waves.

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SUBAREA TITLE - Fluid, Lubricant,
and Containment
MaterialsSCOPE

This subarea encompasses research needed to build a better foundation for the development of new and improved materials for use as functional fluids, lubricants, and elastomeric seals, sealants, and containment devices. Research on synthesis (reactants, routes, mechanisms, conditions, and catalysts for organic, semiorganic, and inorganic reactions and polymerizations) is needed as a basis for the design and development of new materials with tailored molecular structures and compositions that will provide unique combinations of properties. Since the specific molecular structures and configurations, molecular weights and distributions and bulk and surface morphologies of these materials govern their physical, mechanical and chemical properties, fundamental studies of their structure-property relationships are a vital part of this research area. Particular emphasis is also placed on the evolution and development of scientific opportunities for introducing new concepts related to the behavior (fluidity, lubricity, elasticity, etc.) of these materials.

2.4.1 Synthesis and Behavior of Functional Fluids and Lubricants

The performance, reliability, and durability of many aerospace systems depend directly on the availability of improved functional fluids and lubricants. Currently used functional fluids are flammable and lack intrinsic oxidative and thermal stability at high temperatures. There are also significant needs for wider temperature range lubricants and higher temperature greases. Synthesis approaches to new high molecular weight, low vapor pressure chemical systems molecularly tailored to lower flammabilities, increased stabilities, and broader fluid ranges are needed. This also includes research aimed at interrelated synthesis approaches that will lead to compatible chemical compounds which can be admixed with the fluids to improve their stabilities, lubricity, anticorrosion, and flow characteristics and others which can be dispersed in the fluids to increase their viscosities to stable semisolid states of grease consistencies. The synthesis and characterization of new synthetic fluids, for example, polyalphaolefins, silahydrocarbons, polyalkylbenzenes, chlortrifluoro ethylene oligomers, and perfluorinated fluids and associated additives, to improve their chemical and physical properties are required to replace petroleum-based fluids, which may be increasingly more limited in availability in the future, or to meet future system requirements. Fundamental studies aimed at developing an improved understanding of the molecular structure-property relationships of these fluids and lubricants, and an improved understanding of the mechanisms of thermal and chemical degradation under use environments, for example, in the presence of metallic species, oxidizing agents or other substances capable of enhancing degradation, are required to guide future synthesis efforts and to permit prediction of the behavior of these materials in service. The basic principles and parameters governing the behavior of fluids (particularly their viscosities and bulk moduli, their dependence on temperature and pressure, and their correlation

with molecular structure) need to be better understood to guide the synthesis of fluids more suitable for use in future aerospace systems.

2.4.2 Lubrication and Wear

While friction and wear adversely affect the durability of all systems, their impact on the performance and life cycle cost of many aerospace systems is a particular concern. Advanced in the theory of elastohydrodynamics and boundary lubrication are needed to improve current understanding of viscosity-pressure interrelationships, to provide solutions for non-isothermal and non-Newtonian behavior, and to determine and understand the influence of absorbed and chemisorbed surface films associated with boundary lubrication. To understand the complex lubricant-substrate interactions in boundary films, better knowledge of surface topography lubricant rheology, and the role of other lubricant properties and research on the mechanisms of boundary film formation and replenishment are needed. In view of the potential importance of solid lubricants in many aerospace systems, particularly those involving heavily loaded elements operating at high temperatures, improved understanding of the complex nature of solid phase lubricity and its correlation with interfacing surface compositions and structures is needed to guide future developments in this area.

2.4.3 Synthesis and Behavior of Elastomers

Advances in the development of containment materials such as fuel tank and hydraulic system seals and sealants, expulsion bladders, and hoses or other components capable of operating over a wider range of temperatures and pressures will require research on the synthesis and properties of new elastomeric materials. Research is needed on approaches to the synthesis of high molecular weight-polymers specifically tailored in molecular structure to exhibit broad temperature range viscoelasticity by virtue of their low glass transition temperatures and high temperature stabilities. This also includes approaches to the synthesis of new intermediates, disfunctional monomers and multifunctional compounds which can be used to synthesize high polymer network structures with elastomeric properties. New knowledge must be gained of chemical reactions to accomplish this at moderate temperature and without the production of deleterious by-product or catalyst residues. Basic information is needed on the mechanisms responsible for losses of elastomeric behavior in high temperature elastomers operating in severe thermal, oxidative, hydrolytic, radiation, and mechanical stress environments to permit predictions of the behavior of these materials under complex, adverse conditions. Research is also needed to establish molecular structure-physical and chemical property relationships for these materials to guide the synthesis of polymers and oligomers having combinations of properties required for advanced elastomeric materials. The synthesis of newly conceived molecular structures exhibiting useful viscoelastic behavior and long-term stabilities over exceptionally broad temperature ranges will in many cases require new and novel synthesis methods and approaches.

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SUBAREA TITLE - Nondestructive
EvaluationSCOPE

Nondestructive evaluation (NDE) plays a major role in the manufacture and maintenance of Air Force equipment. Emphasis has been on the inspection of components or subassemblies during or following manufacture and throughout the service life as one aspect of the maintenance and repair procedure. The item to be inspected, the service conditions, and the requirements or definitions of acceptability can vary tremendously. Because of this wide latitude in inspection and evaluation tasks, significant advances in NDE capability usually arise out of generic research of physical, chemical, and mechanical phenomena which is directed toward new techniques for the detection of potential flaw like features in a material or component; the study of the mechanisms underlying these phenomena to permit the extraction of quantitative information about the nature of any defects; and studies of the methodology underlying improved accept-reject strategies.

2.5.1 Improved NDE Techniques

Research ideas are sought which have the potential to improve understanding of both existing and new NDE techniques to accurately and reliably detect the existence, formation, or growth of flaws in materials and structures which contain either metals, ceramics, organics, or composites. In addition, totally new NDE methodologies are sought to permit much more accurate and cost effective inspections in areas as varied as manufacturing process control and electronic packaging. The exploitation of evolving technological disciplines in areas other than classic inspection methods is one approach to NDE research efforts in the aforementioned problem areas. Furthermore, research is sought which either enhances the quality capability, i.e. provides a description of the size, shape, and orientation of a flaw for class NDE methods or devices totally new ones.

A task which is as important as the detection of small flaws is increasing the reliability of detection of large flaws. Research is needed which either would show how existing methodologies could be altered to increase their detection reliabilities or to develop new methods, which for instance, might perform the detection task of NDE yet provide no flaw size information. Modeling and analytically describing the NDE process is a critical part of such research. Future efforts will explore the applicability of artificial intelligence techniques to the interpretation of NDE information in order to remove the variability due to human factors.

Subarea 2.5, Nondestructive Evaluation, contains research objectives related to the study of physical, chemical, or mechanical phenomena which could underly new or significantly improved inspection and evaluation techniques for aerospace structures, power plants, and electronic instrumentation. Equally significant to this interdisciplinary technology are studies of such diverse areas as defect-property relations and failure mechanisms to help establish national accept-reject, as well as new sensor/detector development and signal processing methodologies, to name a few.

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the technological opportunities that are now emerging, particularly as a result of the tremendous reduction in cost and increase in computational speed and capacity of computers, suggest an increasing need for interdisciplinary manufacturing research efforts.

In the area of intelligent manufacturing task automation, research is needed on improved models to describe the tasks to be performed, the economic and other productivity implications of the processes to be used, and the means of acquiring, storing, and accessing the data to be used in process planning and control; sensors for visual or other means of part recognition and spatial location, for force, torque or tactile information acquisition, and for the determination of geometric and internal material characteristics as needed to provide information for in-process quality assurance and process control; and control theory, adaptive learning, artificial intelligence and other branches of computer science related to the problem of acquiring and rapidly processing the huge volumes of manufacturing process information that would be available and required for intelligent, self-optimizing, closed-loop adaptive control of flexible, automated manufacturing processes, of advanced robots, and of complex manufacturing tasks such as aerospace system assembly.

Research is also needed in a variety of areas such as data base structure and management, group technology, requirements definition, geometric modeling, generative process planning, natural language interfaces and so on, as the basis for advanced computer aided manufacturing efforts in the future.

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GEOPHYSICS

TECHNICAL AREA

GEOPHYSICS

INTRODUCTION

These Research Objectives deal with research that is required to solve problems resulting from the interaction of Air Force systems and operations with the environment. Problems arise because the state of the environment is not static but varies as a result of natural causes such as solar activity, meteorological phenomena, earthquakes, and so on. The environment can also be artificially modified, say by nuclear weapons detonations, or perturbations of the stratosphere by jet aircraft operations. The varying environment can frequently have a degrading effect on Air Force systems and operations. It is necessary, therefore, that the state of the environment and its effects on systems in a specific area at a specific time be defined precisely and the time of occurrence, extent, and duration of disruptive variations be predictable.

Required research for solution to the problems described in this section comes primarily from the fields of Earth Sciences, Atmospheric Sciences, and Astronomy and Astrophysics, or Space Science. The research involves many subareas such as geology, geodesy, seismology, and remote sensing in the Earth Sciences. It involves weather observations and predictions, weather modification, ionospheric research, visibility studies, atmospheric modeling and advanced infrared sensors in the Atmospheric Sciences. In Astronomy and Astrophysics it involves studies of solar activity, studies of solar emitted particles, and the magnetosphere and magnetic storms, of trapped radiation and particle precipitation, and of magnetic and electric fields between the sun and earth.

See also Project Forecast II initiative PT-12 Full Spectrum Ultraresolution Sensors (section 9.1.5) which focuses on advances in passive and active sensor capabilities, including IR, ultraband radar, spaceborne lidar, and ultraviolet imaging sensors.

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- 3.5.9 Neutral Density and Dynamics

SCOPE

The purpose of this research is to understand and characterize the space environment conditions that significantly impact the survivability, reliability, and operation of space-based systems including surveillance and communications satellites. In order to meet these objectives, research is conducted on the entire solar-terrestrial system. Solar physics research includes investigations of solar activity: x-ray, ultraviolet, optical, radio and plasma and particle emissions. Solar activity is the basic driver of all disturbances of the aerospace environment. The propagation of these solar-initiated disturbances through the interplanetary medium is modeled in order to clarify and understand the mechanisms through which energy is coupled from the solar wind to the magnetosphere. The impact of trapped particles and cosmic radiation on microelectronic systems reliability and lifetimes is examined along with studies of the effects of the interplanetary magnetic field, solar wind, and magnetospheric processes on space systems. Measurements and theoretical studies of the Earth's radiation belts are conducted to assess and predict long-lived effects of nuclear debris. Theoretical and experimental investigations of the ionosphere/ magnetosphere system are required to develop analytical and predictive models of these regions. The models will contribute to the understanding and prediction of the processes triggering geomagnetic storms as well as the intensity and duration of space environment disturbances produced by magnetic storms and substorms. Specifications and models must be developed to characterize the interaction of orbiting spacecraft with the ambient space environment. This includes effects of spacecraft charging and spacecraft contamination on Air Force spacecraft and the development of techniques to mitigate the effects of these environmental interactions. Greatly improved understanding of space environment processes and systems interactions are needed to establish specifications for the design of sophisticated, long-lived satellite systems and large, high-powered structures in space. Active experiments in space have high potential of providing the Air Force with new offensive and defensive tools in the coming decade. Investigations into the consequences of the injection of particle beams, chemicals, and high-power radio waves into the space environment, a laboratory without walls, will result in major advances in the understanding of the space plasma system and lead to the exploitation of space for Air Force operations.

3.1.1 Solar Physics

A growing number of Air Force surveillance and C3I systems operate in the space environment. They can be seriously degraded as a result of solar electromagnetic, particulate, and plasma emissions. Examples of such system degradations include: radar "jamming" by solar radio bursts, astronaut radiation hazards from solar protons, and satellite drag due to heating of the neutral atmosphere by plasma clouds ejected by the sun. Research on solar activity is focused on the flares from active regions and eruptive high speed wind streams from coronal holes. Flares are analyzed at

a variety of wavelengths (gamma-ray, x-ray, ultraviolet, infrared and radio) to obtain a complete self-consistent picture of flare structure and mechanisms. Key areas of research include energy storage, build-up, triggering and release as well as particle acceleration. Coronal holes are studied by ground based radio and optical emissions and shorter wavelength (EUV and X-ray) emissions observed by satellite experiments in order to deduce their structure and evolution. The ultimate goal of such research is to understand, specify, and predict solar activity in order to mitigate its impact on DOD systems.

Since magnetic energy is the main source of free energy for solar activity, basic research on solar magnetic fields and their interaction with dynamical solar processes is conducted to develop an understanding of the physical processes in flares and high speed wind streams. The interactions between small-scale convection (the solar granulation and supergranulation), waves (acoustic and magnetohydrodynamic), and solar magnetic structures provides the energy content and triggering mechanisms for flares and probably the acceleration mechanism for the solar wind and coronal mass ejections. Research to improve our spatial, temporal, and spectral resolution of these small scale processes is required to develop better models that will give a predictive capability for these events. Research on large scale oscillating (global pulsations) and convective motions (giant cells) is required to develop an understanding of how the solar dynamo (generation of solar magnetic fields) works and to determine how magnetic fields are transported from the interior to the solar surface where they can determine the strength, lifetime, and frequency of activity centers, which in turn cause the solar induced environmental disturbances.

3.1.2 Solar Stellar Connection

Since solar activity is the source of most upper atmospheric and space disturbances, it is desirable to obtain long-range forecasts concerning the level of solar activity expected. Observations of solar activity and subsequent modeling are useful in this respect. However, the longterm validity of resultant models and predictions can only be tested by application to other stars showing solar-type activity. It is thus desirable to obtain data on stellar activity such as flares and stellar chromospheres by use of spectroscopic and photometric observations. In addition, it will be instructive to compare satellite observations of the total energy output of the sun (the solar constant) with the output from a large number of stars near the sun on the main sequence of the stellar evolution diagram to accurately assess the prospects for and evidence of longer term (solar cycle) variability of solar energy output.

3.1.3 Interplanetary Research

The solar wind and interplanetary magnetic field determines the size, shape and energetic particle content of the magnetospheric/ionospheric cavity. Of particular interest is the propagation of structures (streams, flare disturbances, discontinuities, etc.) and shock fronts in the solar wind that cause geomagnetic storms. These propagating disturbances are remotely sensed by a variety of techniques including interplanetary scintillations of background stars, low frequency (kilometric) radio measurements, and satellite based white light photometers and coronagraphs. Research on transient, corotating, and compound solar wind streams will increase our understanding

of processes by which energy is transported through the interplanetary medium and coupled into the magnetosphere. Research is required to increase our understanding of the role of the solar wind and interplanetary magnetic field in triggering substorms. Research is needed to understand the interplanetary propagation of solar and galactic (background) energetic charged particles that pose a hazard to manned and unmanned space flights and missions.

3.1.4 Magnetospheric Dynamics

Air Force space systems operate in a dynamic and hostile environment. Mission research objectives require knowledge of the basic physical mechanisms controlling magnetospheric particle input, transport, and loss. These mechanisms depend on the magnetic and electrical structure of space and associated plasma processes. Operational malfunctions from space-systems interactions with plasmas include radiation degradation of electronic components on board spacecraft, electromagnetic signal interference due to modification of the ambient and intervening environment, and electrostatic discharge-generated anomalies due to spacecraft charge buildup.

Radiation degradation is directly related to the life-cycle cost of operational space systems. These effects are dependent on the charged particle population and magnetic field configuration in the interplanetary medium and the earth's magnetosphere.

A time varying magnetospheric model is needed in order to predict magnetic activity generated effects on the particle population encountered by future operational systems. The model should track the progress of a substorm and should be driven by IMF controlled boundary layer coupling and merging processes in the tail. Real-time monitoring of the solar wind parameters are critical to a predictive capability.

Ionospheric response to solar activity is influenced by energy deposited by magnetospheric processes. The development of predictive ionospheric models is largely dependent upon understanding the phenomenology of magnetospheric-ionospheric coupling and the associated energy transfer. The ionosphere, in turn, becomes an interactive boundary condition on all magnetospheric processes. Research is required into the activity of the ionosphere under all conditions and at all times and its link to magnetospheric behavior. Understanding the exact nature of this coupling is necessary for greatly improved specifications of magnetospheric hazards at geosynchronous orbit which change with magnetic activity and specifications of ionospheric behavior and its systems impact such as spacecraft charging and discharge, satellite drag, optical/infrared emission enhancements, and communications/surveillance response to electron density irregularities.

3.1.5 Active Space Environment Control

The introduction of small quantities of chemicals, waves or particle beams can profoundly alter the properties of host plasmas by catalyzing the release of stored free energy. Systematic variations in the energetic electron contents of the radiation belts through interactions with natural VLF backgrounds is a well understood example. Theoretical concepts for actively controlling the energetic ion contents of the belts using ground-based HF radiation sources must be

developed. The ability to control the ion content would allow the selection of radiation free orbits for surveillance satellites through the belts. Research is required to identify and exploit other free energy sources in natural plasmas that can be used to enhance military operations in space environments. The wave emitting properties of particle beams must be studied as sources of VLF for radiation belt control, as antennas in space and for remote diagnosis of directed energy weapons' propagation characteristics. Innovative methods must be developed and tested to allow charged and neutral particle beams to co-travel across magnetic fields in space, thus maximizing their flux on deposition regions. Project Forecast II has identified revolutionary technologies for using high power HF radiation to accelerate electrons to relativistic energies in space. Theoretical, laboratory and space flight tests need to be conducted to test the feasibility of these theories and concepts.

3.1.6 Spacecraft Environment Interaction

Research is needed to quantify the effects of natural and man-made particle streams in the near-earth and space environment and their impact on spacecraft charging. Spacecraft charge up to very high potentials with a subsequent discharge which causes failure of certain electronic components. Natural spacecraft charging has coincided with geomagnetic substorms. To understand the interactions between the disturbed environment and the spacecraft, it is necessary to make in situ measurements of plasma conditions around the vehicle, and of the level of electrical charging occurring during disturbed conditions. Computer-based models will be developed to quantify the charging process.

In order to develop a dynamic model of the high energy particle environment, in situ measurement of the flux of energetic electrons, ions and protons together with electric and magnetic field measurements should be made throughout the near-Earth space environment for various levels of solar activity. The results will be used to specify the degradation of electronic devices in terms of orbital parameters to enhance system lifetimes and prescribe the shielding necessary to satisfy operational goals. In particular, methods to determine the effect of the natural space radiation on satellite-borne microelectronic components are needed. Improved models are needed to specify and predict radiation levels to support Space Shuttle operations and study the interaction of the Space Shuttle with the space environment.

3.1.7 Spacecraft Contamination

Spacecraft contamination in the form of particulates, gases and radiation generated from the spacecraft can pose a threat to the operation of surveillance and weapons systems. The measurement of such contamination is needed as a function of position around the spacecraft and as a function of time. Along with such contamination measurements, appropriate contamination models should be developed to enable the Air Force to design and locate its spacecraft systems for minimal contamination effects.

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SUBAREA TITLE - Optical/IR
Environment
ResearchSCOPE

This subarea relates to research on optical effects in communications, surveillance, navigation, and detection involving a wide range of basic investigations leading to the optimization of the design and performance of military systems operating on both quiet and perturbed atmospheric environments. This objective requires research specifically in the areas of optical/infrared spectroscopic and sensor techniques and concepts, spectroscopic studies, atmospheric absorption and scattering, theoretical studies of basic molecular interactions, atmospheric modeling, nonequilibrium radiative phenomena, background radiance, lasers, target signatures of plumes and laser-irradiated targets, and the interaction of plumes with the atmosphere. Research in the area of remote sensing of atmospheric and meteorological parameters by infrared and millimeter wave techniques is also a requirement.

3.2.1 Atmospheric Transmission/Absorption

Research leading to the development of more sensitive spectrometric techniques and sensors is required because the spectral characteristics of the atmosphere and environment must be known to determine their effects on military systems which operate in the atmosphere or look through it. As detector sensitivities increase, better knowledge of the properties of the atmosphere is required to optimize present and future detection and surveillance systems. High resolution laboratory and field measurements of atmospheric species (including trace gases) need to be obtained. Research leading to the development of high-resolution cryogenically-cooled interferometers is needed and novel spectrometric techniques should be studied for applicability to military missions. This will include research in field-widened interferometry using mosaic focal planes as the state-of-the-art in detector arrays advances. The novel technique of Ion Cyclotron Resonance mass spectrometry (ICR) should be studied for its multiplex advantage and eventual coupling with its counterpart infrared Fourier Transform Spectroscopy and for its potential applicability to balloon-borne measurements. Studies of optical background suppression schemes are needed to enhance the effectiveness of military optical/IR surveillance systems. Continued laboratory and field spectroscopic measurements of atmospheric constituents will still be required to update the AFGL line compilation which is used DoD wide for optical/IR transmission calculations. The high-resolution data are needed for the prediction of laser propagation in the atmosphere. These data also are required for the assessment of the performance of narrow field-of-view, narrow spectral bandwidth, heterodyne detection systems.

In conjunction with the spectrometric studies, there is a need for research on theoretical and computational techniques for determining relevant molecular parameters. These parameters include molecular energy levels, line intensities, transition halfwidths, and the shape of molecular absorption lines under atmospheric conditions. Research is also required on improved methods of

calculating spectra from theoretical line data. A theory of molecules needs to be developed that will enable the calculation of all the required molecular transitions from a limited set of molecular constants. Research needs to be performed on molecules with a high degree of symmetry such as methane.

The theoretical studies are needed in order to predict the transmittance and radiance effects of the atmosphere. In order to have the relevant parameters for the range of pressure and temperature encountered in the atmosphere, the calculations must be performed theoretically. The theoretical calculations must be consistent with the spectrometric observations for the conditions under which the observations were made. This research must cover the spectrum from visible through infrared to the microwave region. The need for this research is particularly great in order to keep the AFGL line listing current and applicable for laser propagation in the atmosphere and for path radiance in the upper atmosphere.

3.2.2 Auroral and Nuclear Background

Research in this area should directly investigate the background limitations of aurora and airglow on infrared systems and enable extrapolation to the nuclear case. Laboratory cryogenic chamber experiments, laser pump-and-probe experiments and in-situ rocket and satellite measurements provide new data for predictive chemistry codes. In addition, the new measurements provide a data base on the actual spectral, spatial and temporal characteristics of infrared/optical atmospheric emissions in the natural environment. This data base is used as a guide to extrapolate to the radiance levels to be encountered in a more severely disturbed atmosphere. Laboratory experiments are needed to simulate severely disturbed atmospheric conditions to validate extrapolation.

Advanced infrared surveillance and weapons systems require research on interfering disturbed atmospheric backgrounds which have unusual spectral, temporal and spatial characteristics. Survivability during conflict for space-borne surveillance and communication systems means not only physical survival, but that they must operate in some meaningful fashion. These interfering backgrounds can prevent this by creating unacceptable noise, false targets and/or saturation of the optical sensors. The research goal is to enable, by partial simulation in the laboratory and in the atmosphere, the computer modelling of the infrared/optical atmospheric background radiation to be expected under both natural and nuclear detonation perturbed conditions. Improvements which are required include more reliable, precise, and efficient techniques for producing and exciting reactive molecular species, particularly by electron and laser beams, and for detecting them and their resulting radiation. New techniques for radical/ionic confinement for optical investigation are required. Continuing synoptic observation of aurora with improved instrumentation providing greater sensitivity and temporal and spectral resolution is also required.

Data on the production and loss mechanisms for atmospheric infrared species are utilized in the AFGL OPTIR code which models optical and infrared effects under a variety of excitation conditions. The data are also used in the Defense Nuclear Agency Radar-Optical Systems Code (ROSCOF). The codes provide estimates of the nature and intensity of the atmospheric infrared backgrounds against which present, proposed, and future infrared surveillance systems must function. Prediction of infrared backgrounds is essential for assessment of system considerations such as optimal operating wavelength, optical bandwidth, spatial filtering techniques, and target to background contrast ratios.

3-2-3 Natural Airglow

The spectral content of the airglow and its perceived brightness fluctuations constitutes the lower baseline against which a limb-viewing detection or surveillance system must operate. An extensive carefully assembled data base of airglow observations is required to enable system designers to avoid either excessive false alarm rates or a too severely constrained sensitivity. Infrared/optical radiation from the quiescent atmosphere should be studied by ground, rocket, and satellite-borne sensors to determine the spectral, spatial, and temporal distribution of the normal airglow, both in the sunlit and nominally dark atmosphere. The research goal is to provide a confident statistical account and separation of the known patchiness and regular variability of the airglow into spatial and temporal components for selected spectral bands. There is also a need for more sensitive measurements with increased spatial and spectral resolution for use in the development of advanced state-of-the-art sensors.

3.2.4 Celestial Backgrounds

Research in this area is needed because LWIR systems designed to detect space-borne objects must view their targets against the natural infrared celestial background. Stars, Compact HII regions and asteroids can appear as false targets in these systems. Moderate sized advanced state-of-the-art cryogenically cooled sensors need to be flown to obtain survey data in the LWIR spectral region. The spatial and brightness distributions of a representative sampling of the classes of objects which emit strongly in the infrared need to be obtained. There is a need for an increase in the survey data base to greater sensitivity with satellite experiments. The spectral, spatial and temporal signatures must be defined to permit development of effective discrimination techniques.

3.2.5 Near-Earth Background Radiance

Infrared systems operating in near-horizon scanning modes must discriminate against the infrared background radiance from the atmosphere. In order to provide background data for proposed future systems we require measurements several orders of magnitude more sensitive than those currently available. We require measurements of the infrared radiance of the earth's atmosphere, particularly in the upper region where essentially no data are available. From these data we must construct an atmospheric model which will describe vertical and horizontal distributions of radiation, diurnal as well as seasonal variations, fluctuations, and correlation distances. There is a need to extend these measurements to sufficiently sensitive radiance levels such that the diffuse zodiacal radiance becomes the limiting background phenomenon.

3.2.6 Atmospheric Transmission of Target Signatures

With the development of advanced infrared detection techniques, new and sophisticated military target detection systems are under development. The success of these systems relies on the ability to discriminate and identify the desired target type from false targets and from natural and man-made backgrounds. The sensitivity of such systems will be such that a new level of knowledge and

prediction capability is needed. The ability to predict the optical and infrared signatures of rocket and aircraft engines when viewed from any aspect angle is required. Studies on the effect that the spectral degree of coherence across the source has on its far-field spectral distribution are needed to ascertain the validity of target signatures. An adequate prediction of background signatures that will affect detection and discrimination techniques of such plumes is also required. There is a need for more sensitive instrumentation with better spectral and spatial resolution and more effective discrimination techniques.

Research is needed in the area of laser signatures to investigate the influence of atmospheric properties of laser scattering. It is also necessary to model more adequately the effects of atmospheric turbulence on a laser system to separate target speckle from atmospheric induced speckle. Further research is needed in laser speckle to provide a means for predicting what the speckle pattern and statistics will be for any given situation, especially for those with complex target shapes. Speckle can result in a spurious modulation induced on the radiation reflected by a target and is a function of target surface geometry, finish, and other scenario parameters.

3.2.7 Theoretical Molecular Studies for Background/Targets

The determination of the emission from hot molecular sources such as plumes, aurora, and other targets is required. Methods of discriminating these targets against backgrounds and an intervening atmosphere is in need of significant effort. Research is needed to extend the validity of molecular calculations to higher rotational and vibrational energies. These states are of importance in the emission of molecular systems at elevated temperatures. Research needs to be performed on faster computational techniques for calculating the propagation of emitted energy through the atmosphere. The effects of collisional and Doppler broadening need to be included. Significantly, new formulations of the treatment of molecules at high temperatures need to be explored.

3.2.8 Plume Atmospheric Interactions

Discrimination of targets at high altitudes requires knowledge of the plume/atmospheric interaction parameters, since the magnitude of infrared radiation and the spectral band shape of the radiation depend strongly on the mode of excitation. There exists a need for an experimental program to study the inelastic collisions of major plume species with atmospheric constituents, leading to emission of infrared radiation. Reliability of high altitude plume models which are used for analysis and prediction of target signatures, and consequently the missile surveillance systems, depends to a large extent upon knowing the efficiency of the reactions.

3.2.9 Optical Aerosol Modeling

The need for atmospheric optical models arises from the military requirements for evaluating and predicting the performance of various visual, electro-optical and infrared systems, and what effect the atmospheric optical/infrared attenuation properties will have on such systems in operational environments. Such predictions are needed in a statistical sense for systems performance analysis studies, and also on a real-time basis for operational weather forecasting support. Models of the optical properties of aerosols are needed, which allow the user to calculate such parameters as beam attenuation, angular scattering

intensities, polarization, path radiance and contrast transmission. These models require as inputs particle refractive indices, size distributions, and concentrations. Experimental and theoretical studies are needed to determine and formulate the dependence of these quantities on meteorological and environmental conditions. Radiative transport and multiple scattering codes must be developed which can be used to compute for the aerosol models the various specific optical propagation parameters. It is important to derive for these optical models a statistical data base giving the models a probability or frequency of occurrence as a function of geographical location and season or time period. For operational purposes it is also necessary to derive relationships between the optical quantities and transmission models and the general meteorological variables.

3.2.10 Remote Sensing of Atmospheric Quantities

Considerable effort has already been expended by both the civilian community and the military to develop satellite sensors and analysis techniques for vertically sounding the atmosphere in terms of temperature and humidity. These quantities are needed for global and mesoscale weather forecasting and real-time decision making regarding the deployment of specific tactical and strategic systems. There is a research need for satellite-borne sensors to measure meteorological parameters (such as the three dimensional structure of atmospheric temperature, water vapor, cloud structure, and wind patterns) and trace atmospheric constituents. The specific needs include both the development of advanced sensors (or sensor concepts) and the data analysis techniques for inferring the atmospheric quantities from the measured radiances. There is a need to obtain meteorological data at any point in the world from a satellite platform, thus eliminating the requirement for in-situ radiosonde and rocketsonde measurements, and for tracking trace atmospheric constituents by air sampling and ground-based methods.

3.2.11 Optical Turbulence

Optical turbulence can affect optical systems, such as laser systems, that send signals through the atmosphere. The determination of the magnitude of this turbulence and its variation with position and time are needed in support of these optical systems. Among the parameters that need to be measured are the optical turbulence parameter, the coherence length, and the isoplanatic angle. Along with these measurements, optical turbulence models should be developed.

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SUBAREA TITLE: Ionospheric
ResearchSCOPE

This area of research aims to define the physical and chemical properties of the earth's upper atmosphere and ionosphere and to determine the effects of these properties on Air Force systems operating in or through these regions.

3.3.1 Ionospheric Physics

The goal of ionospheric research is to achieve an understanding of the physical processes which occur in the earth's ionosphere and to reduce that understanding to a quantitative description of ionospheric behavior. Specific areas for required research include: methods for detailed calculation of electron density profiles resulting from solar illumination and/or precipitating particles; methods to derive electron density profiles from airglow and auroral emissions as measured by satellite techniques for time dependent forecasts of electron densities valid for three-to-six hours; investigations of ionospheric responses to magnetospheric and interplanetary variations; development of detailed empirical models to represent the ionosphere using comprehensive data; investigations and studies of ionospheric variability resulting from plasma oscillations and instabilities and wave-plasma and electron-ion beam-plasma interactions. The results from the above efforts will be adapted and used for support to ionospheric dependent or affected Air Force systems.

Research is required to establish a morphological understanding of the occurrence of VHF-to-SHF ionospheric-caused phase and amplitude scintillations. Research statistics are required as the basis for design and for developing operational procedures to mitigate the effects of scintillations on transionospheric radio wave propagation systems. Studies are also needed to establish relationships between scintillations and solar geophysical causative mechanisms. Research should emphasize studies of auroral, polar cap, and equatorial scintillation phenomena; these are the regions which experience the most frequent and severest scintillations.

Another goal in ionospheric research is (1) to define and understand the behavior of total electron content (TEC), which is proportional to time delay, and its variability over the entire world, and (2) to apply this to current and proposed Air Force radar and radio ranging systems. The statistics of the variability of TEC, and its rate of change, must be determined as a function of geographic location, time of day, season and state of solar, and magnetic activity. Relationships to foF2 and to other geophysical parameters must be established.

Additional research is required to determine the coherence time of the ionosphere for phase coherent radar tracking. This effort is limited by lack of experimental data, but the climatological approach will prepare a much needed foundation for future support to both ground-based and space-based coherent radar tracking.

3.3.2 Ionospheric Disturbance

The goal of this research is to understand the physics and chemistry of natural and artificial disturbances in the ionosphere that may affect electromagnetic wave propagation from VLF to EHF frequencies. Ionospheric parameters such as conductivity, charged particle composition, and overall structure are measured in-situ with a variety of techniques. Mass spectrometers and other instruments are flown on balloons, rockets, and satellites into natural disturbances such as aurorae, magnetic storms and polar cap absorption events. In the ionospheric perturbation program, the structure and properties of the ionosphere are intentionally changed to study the possible enhancement or degradation of communications and surveillance systems. Chemical releases, ground-based RF oblique heating, microwave heating, and space-based perturbation techniques are several of the methods used.

3.3.3 Atmospheric Chemistry

The principal goal of this effort is the determination of the chemistry required in predicting and exploiting the effects of perturbations on the ionosphere and other plasmas. Of particular interest is the chemical modification of free electron densities in the ionosphere, missile plumes, reentry wakes, and flames. The parameters needed are the rate constants for chemiionization, electron attachment, and electron detachment reactions, together with such thermochemical quantities as electron affinities and bond dissociation energies. These parameters are determined in laboratory experiments and in quantum chemical calculations. Measurements are required over a wide range of both temperatures and translational energies. Candidate chemicals for plasma modification experiments are evaluated theoretically with the aid of computer models of the phenomenology and experimentally in both ground level and field tests.

3.3.4 Ultraviolet Radiations

The principal source of energy into the earth's upper atmosphere is the ultraviolet (UV) radiation coming from the sun. This radiation is the chief source of heating and ionization of the upper atmosphere and directly influences the structure and character of the ionosphere. Additionally, many processes occurring in the ionosphere, produce ultraviolet airglow radiation. It is anticipated that a study of the ultraviolet and associated processes, will enable the Air Force to use UV technology to remotely measure the electron density distribution in the ionosphere and to locate auroral regions, for the purpose of specifying radio propagation conditions throughout the world. UV measurements of missile and associated backgrounds are also being made for use in missile surveillance and tracking. This work will eventually provide the Air Force with a lower cost alternative to existing IR surveillance systems.

3.3.5 Plasma Defense Technology

The goal of this effort is to develop the technology required for (1) the controlled formation of artificial ionization in the atmosphere and ionosphere (Artificial Plasma Technology (APT)), and (2) the acceleration of electrons in the ionosphere to very high energies, along with their containment along the geomagnetic field lines (Energetic Electron Technology).

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SCOPE

The increasing technical sophistication of Air Force operations and systems has made them increasingly susceptible to the geodetic and geophysical environment. This research incorporates a wide range of geodetic and geophysical techniques and related instrumentation necessary to compensate for these effects and optimize the mission capability in such areas as surveillance, reconnaissance, target acquisition, weapons delivery, missile siting, etc. This objective requires research in geodesy (position determination, parameters relative to the shape, size and dynamics of the earth); gravity (measurement and modeling of the potential); geophysics (environmental noise, surface loading and earth rotation); remote sensing (geologic applications); and hydrology.

3.4.1 Geodetic Research

To deliver an inertially guided missile from launch site to a remote target, one must know the launch site and target coordinates with respect to the same earth centered reference system, the astronomic coordinates of the launch site, the gravity field along the entire trajectory and especially close to the launch region, and the magnitude of the gravity at the launch site.

Research in these areas must anticipate Air Force requirements of the next decade and beyond. The incorporation of new concepts in inertial weapons delivery will be impractical without such research. Objectives such as improved accuracy, all azimuth launch capability, longer trajectories, and changing launch sites and targets all impact the nature of the research which must be performed now. The approach in formulating the research program for geodesy, gravity and geophysics is to concentrate on those items of a missile's error budget that are dominant and that will be amenable to cost effective improvements. In geodesy this research must address the basic theories, instrumentation concepts, and the measurement of geodetic parameters. One of the requirements for the improvement of ballistic missile CEPs is the improvement of the accuracy of astronomic and geodetic position determination. A broad program of research into earth rotation and polar motion and near real-time accurate world-wide geodetic positioning is required. New efforts must be made to use the Global Positioning System for geodetic positioning. One potentially valuable approach being pursued is the use of radio interferometry to rapidly determine high precision relative positions of ground stations. Great improvements in speed, accuracy and cost reduction in geodetic surveying are the goal of this work. To achieve requisite accuracy in ground positioning corresponding improvement in GPS orbits are required. Further research will concentrate on radio interferometric techniques to refine GPS tracking capabilities. These approaches should be highly applicable to the massive surveying problem anticipated in siting in fixed or mobile ICBM launch positions, shelters, and command posts.

The expected increase in requirements for high precision global reconnaissance, target acquisition and weapons delivery will continue to generate new research objectives and intensify research in many existing programs. Geodetic goals, especially for definition of dynamic parameters of the earth, will have a significant impact on long-range research on advanced inertial sensors.

3.4.2 Gravity Research

Improved capability is needed to model the earth's gravitational field on the earth's surface and near-earth space and to expand existing gravity coverage into sparsely measured areas of the world. Inertial navigators must have an accurate mathematical model of the gravity field in order to separate inertial and gravitational effects. Further advances in inertial navigation performance cannot be made without a solution to this gravity problem. The determination of the most effective and economical methods of modeling the earth's gravitational field are the objectives of gravity research. Moving base platform instrumentation (gradiometer), satellite altimetry, and satellite-to-satellite tracking will be developed as potential data acquisition techniques. GPS receivers and inertial instruments aboard STS will allow global gravity field values to be derived, including coverage of polar and politically inaccessible areas. Superconducting inertial instrumentation will provide more accurate, compact guidance systems that will operate autonomously, without prior knowledge of the gravity field. Recent findings of particle physics and measurements of gravity in mines suggest that fundamental laws of gravity and the value of G (Universal Gravitational Constant) may need revision. Extremely careful gravity measurements will determine the validity of these hypotheses.

3.4.3 Earth Motion Research

Advanced Air Force weapon and support systems, operational and test facilities, and military operational area (MOA's) have become increasingly sensitive to earth motions as weapon accuracy and environmental impact requirements have become more demanding. Air Force activities and operations themselves can produce ground motions with the potential to adversely affect its own or other military or civilian facilities or provide compromising intelligence data. These situations require a comprehensive understanding of both the natural and induced motion environments for Air Force systems to provide the basis for developing methods to forecast motion effects and to assess consequential effects of Air Force operations. A broad range of geophysical research will be required to achieve this goal. Studies are necessary to model and predict both non-propagating (earth tides, wind-induced ground motion) and propagating (seismic) motions so that the effects may be incorporated into system design.

Long-period motions affect the testing and pointing accuracy of multiple system types. Research is required to determine the response of the earth's surface to external forces (such as atmospheric pressure variations and moving vehicles), the expected motions resulting from internal forces, and physical properties of the near-surface crust of the earth. Extensive work is required to develop a methodology to reliably measure long-period and aperiodic displacements and rotations. GPS, VLEI, long-period, low noise seismometers, and long-base tiltmeters show considerable promise as tools for achieving these goals, and will be developed for this purpose.

Seismic motions are generated by or impact many Air Force systems affecting error budgets that become proportionally larger as accuracies increase. Research should be conducted in three major areas: (1) source characteristic determinations, (2) seismic wave propagation attributes, and (3) local site effects. Research on the motion source will include analysis of the spatial and temporal characteristics of earth noise and seismicity, seismic source functions for earthquakes and explosions, and acoustic-seismic coupling. Problems of seismic wave propagation through complex geological media will be investigated using computer simulation techniques, with the aim of identifying geophysical and geological parameters having significant impact on military detection, identification and motion problems. Methods for rapid, in situ evaluation of underground structures will be explored using very high frequency seismic waves. An improved capability is required to define seismic detection and discrimination for the surveillance of nuclear test-ban treaties including seismic, hydroacoustic, and infrasonic techniques. Improved understanding of seismic wave propagation and attenuation at regional and teleseismic distances is necessary for effective test-ban treaty monitoring and earthquake ground motion predictions.

3.4.4 Earth Crustal Research

Siting of ICBMs safe from nuclear attack is a major Air Force problem. The basing of ICBMs will require research in nuclear blast cratering potential, energy absorption of crustal rocks, motion of blocks of crustal rocks, and rapid rock excavation for ICBMs egress. Nuclear blast simulations using high explosives need improved comparison methods and techniques. Remote sensing for geological evaluation of ICBM sites is a promising area of research.

Basic research in hydrology is needed to understand underground water movements. Rapid Deployment Forces need water for human consumption and operation of equipment. Research in simple and rapid methods of finding water are mandatory. The Air Force must protect the environment, especially ground water, when using or storing radioactive and toxic materials.

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SCOPE

Atmospheric effects on Air Force missions is of extreme importance for systems design and mix considerations such as deployment, launch, target detection, acquisition and destruction, communications and recovery. The research identified by this subarea is aimed at specifying and predicting meteorological factors which pose threats and/or opportunities to that mission. Today, as much as any time in the past, it is becoming ever more critical to be able to specify meteorological parameters both spatially and temporally, anywhere on the Earth. New satellite sensing techniques play a key role in meteorological parameters retrieval over oceans or data denied areas. The inclusion of weather observations into numerical prediction models will result in real-time mission support. There are many atmospheric phenomena which thus need to be specified and predicted.

3.5.1 Large-Scale Dynamics/Prediction

Improved methods of predicting weather elements affecting Air Force operations demand a better understanding and increased capability to model the entire scale of atmospheric dynamics and interactions. On the large scale, planetary waves develop from the available energies due to solar insolation, the heat stored in oceans and land surfaces, and latent heat. There are numerous feedback processes involving cloud cover, and release of latent heat radiation. There are also coupling and interaction between these largescale phenomena and smaller scale features as well as with the upper atmosphere. These feedback mechanisms, interactions and couplings need to be better understood in order to increase our large-scale forecasting capabilities. Force mix, deployment planning, and weapons selection decisions could benefit greatly from such global and regional weather forecasts. These large-scale phenomena must also be understood to improve shorter period forecasts.

3.5.2 Intermediate-to-Small Scale Dynamics/Prediction

A lack of basic knowledge exists concerning medium (meso) scale dynamics, its interaction with the larger scale phenomena, and our ability to model and predict weather phenomena of limited geographic extent. A standing requirement exists for improvement in understanding the atmospheric physics in representing it in conceptual models to clarify the fundamental processes involved. Improvement in associated mathematical techniques will permit incorporation of the physics into numerical prediction models. Specific needs include better parameterization of the effects of heat, momentum, and water vapor transfer through the boundary layer, the effects of terrain, land/water boundary factors, ground cover and surface roughness. Radiative and photochemical processes must be accounted for. Concurrently, a need exists for improved numerical procedures so as to yield fast and accurate numerical solutions of the model equations. Consideration of methods to couple (or

nest) mesoscale prediction models with global and/or large regional scale models need to be evaluated. The lack of physical understanding and the ability to model the mesoscale severely limits mesoscale space and time scale (tactical) prediction and also greatly limits the longer period predictions. The limits of predictability of different mesoscale phenomena (e.g., severe thunderstorms, squall lines, locally heavy rain/snow, low stratus and fog) need to be established through theoretical and experimental studies. Through the simultaneous monitoring of weather on large and small scales, a better understanding of the mechanisms and processes through which scale interactions (which influence phenomena predictability) occur will be established. Atmospheric effects on microwave propagation, target forecasts, the diffusion and transport of nuclear debris and chemical/biological warfare substances, and artillery fire corrections are examples of areas which require this scale of meteorological information.

3.5.3 Cloud Microphysics

Improved specification of the numbers, size distribution and types of cloud particles, ice crystals as well as liquid water droplets are required for studies of missile targeting effects for assessing the degradation of aerospace laser and microwave weapon/communication systems, and for studies of icing relevant to cruise missiles and ground support aircraft. There is a serious lack of knowledge concerning the spatial and temporal distribution of these hydrometeors. This lack of reliable specification jeopardizes the usefulness of weapon/communication systems currently being utilized, designed and developed. Therefore, the requirement exists for understanding these cloud physics parameters, for developing and testing theoretical precipitation growth models, models of the melting layer and models of atmospheric icing, and for providing statistical, climatological information as a basis for both design and operation of weapon systems. Requirements are for both a climatology and real-time forecasts of particle distributions in all types of clouds, for new instrumentation specifically designed to provide cloud physics data for advanced weapon/communication systems, and for improved models of precipitation growth and of atmospheric icing conditions.

3.5.4 Physics and Dynamics of Precipitation Systems

Research is required on the dynamics of stratiform and convective precipitation systems, including air motions both within clouds and in surrounding cloud-free areas. Of particular concern to Air Force operations are the dynamical processes leading to the development of tropical storms, tornadoes, and other hazardous storm conditions. Interrelationships of storm dynamics and hydrometeor microphysics should be explored by means of numerical models and experimental data from satellites, aircraft, radars, and other sensors. These efforts should yield improved understanding of the evolution of hydrometeors in storms, including the development of icing conditions and hail, and lead to improved predictions of hazardous weather conditions. An aspect of this technical area in need of particular emphasis is the development of the capability to measure the intensity, direction of motion, and detailed structure of tropical cyclones by means of current and future remote sensing systems for satellite platform and ground based radar systems.

3.5.5 Atmospheric Electricity

The increased use of composite materials in airframes and the greater reliance on solid state electronics in airborne weapon systems have increased the lightning and static discharge problems. Aircraft skins of composite materials will not easily dissipate the power levels associated with lightning nor provide a Faraday Cage environment for internal electronics. Knowledge of the power and frequency content of lightning will facilitate design of protective measurements while knowledge of the charging/discharging physics within clouds might permit cloud management through modifications. Knowledge of the charging processes, charge separation dynamics, and charge breakdown mechanisms in the atmosphere is needed to better understand such phenomena as triboelectrification, lightning, and the influence of electric fields on the cloud processes. The dependence of droplet/droplet or droplet/crystal collisional charge separation in temperature; the creation of ionized channels for lightning, and the energy spectrum of lightning discharge, are also examples of the research required.

3.5.6 Boundary Layer Dynamics

Improved prediction techniques of those meteorological parameters in the atmospheric boundary layer that affect Air Force operations and systems are required. Such parameters include vertical temperature and moisture discontinuities and turbulence. These parameters affect communications and surveillance systems and the dispersion of both planned and inadvertent toxic chemical releases. To obtain a better understanding of the atmospheric boundary layer physics, it is necessary to develop a modeling capability for the simultaneous transport of heat and water vapor over non-uniform terrain with non-uniform surface distribution of heat and moisture flux and of roughness.

3.5.7 Climatological Modeling

A program in climatological research is needed to improve the probability of success of Air Force missions. There are two aspects: one to provide the probabilities of multiple events in time and space, that could enter into long-range planning, the other to provide simulations of meteorological conditions in the near term. Such research must fill in the gaps of existing climatologies through development of models of events and conditions, such as the appearance and disappearance of clouds, including shapes and sizes, both in the horizontal and in the vertical, and their optical density. New or untried statistical techniques should be pursued such as fractal geometry, which are now feasible, because of recent breakthroughs in computer programming, satellite imagery and radar photography.

3.5.8 Satellite Meteorology

Air Force operations, global in scope, create requirements for an expanded and unique meteorological observation network. Indispensable to such a network is data gathered by weather satellites. Satellites allow for observations in remote areas of the world, including the oceans, as well as a denser network of observations in areas where ground stations are already present. The possibility also exists for substituting the relatively expensive ground-based measurements altogether for parameters that can be adequately measured by satellites.

The development of measurement concepts for specific meteorological parameters, such as cloud cover and type, temperature, wind direction and speed, aerosols and humidity is a necessary part of the Air Force satellite meteorology program. Active sensors such as lidars and radars need to be developed for use on satellites in order to obtain the meteorological measurements with the required accuracy and resolution. In addition, new algorithms are needed to make optimum use of the information from the active sensors. With the new satellite sensing techniques, the Air Force will be able to depict and forecast meteorological parameters with greater precision particularly in data-sparse or data-denied parts of the world. An area of satellite meteorology where increased emphasis is particularly required relates to the characterization and tracking of tropical storms. The longer term objective of satellite meteorology is to develop numerical weather prediction models which rely on satellite data.

3.5.9 Neutral Density and Dynamics

The structure and dynamics of the upper atmosphere have a direct effect on laser systems, radar systems, reentry systems and orbital transfer systems. Measurements of the appropriate upper atmosphere properties in real time is needed so as to make such information available to a given system that needs them. Among the properties that need to be specified in real time are density, temperature, winds, minor species such as water vapor and path integrated optical scattering.

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AEROSPACE VEHICLES

TECHNICAL AREA

AEROSPACE VEHICLES

INTRODUCTION

Present and future Air Force vehicles cover the aerospace performance and environment spectrum from vertical takeoff and landing to orbital flight and hypersonic reentry. Correspondingly, aerospace vehicle design, development and employment requires support from a sweeping cross section of technology and science. The interdisciplinary nature of aerospace vehicle design is such that technology-base deficiencies degrade all system parameters, while tech-base advances often synergistically interact to generate quantum-jump improvements in system effectiveness. To meet future needs, research in structural mechanics, aerodynamics, flight control and vehicle integration and operation is necessary. It should be borne in mind that the Subareas and Research Objectives will contain unavoidable (but hopefully minimal) overlap.

See also Project Forecast II initiatives PT-21 Cooling of Hot Structures (section 9.1.9) and PT-24 Hypersonic Aerothermodynamics (section 9.1.10). These initiatives both target basic and applied research in support of hypervelocity flight vehicles.

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SCOPE

The Structural Mechanics Subarea is concerned with all aspects of structural behavior of aircraft, missiles and spacecraft in all performance, environment and threat regimes. Research efforts under this Subarea should provide the technical and scientific base for analysis, design, manufacture, inspection and maintenance.

4.1.1 Durability

Durability of structural components has a major impact on the economics and long-term performance of aerospace vehicles. Design trade-off between performance and safety requirements need understanding of the failure processes and indicators in structures and engineering materials along with reliable analytical prediction methods. Maintenance schedules, designed to detect signs of potential failures, require a prior knowledge of failure indicators and nondestructive experimental techniques (NDE) for identifying them. Maintainability will be further enhanced with the development of smart skins, structures with sensing devices imbedded within the structural material. Research to address this objective is needed to provide a basic understanding and improved predictive methods for the failure processes in structures and engineering materials, including the identification, characterization and analytical modeling of critical parameters. The failure processes include property degradation (residual strength), fatigue damage accumulation, crack initiation and propagation and fracture. Critical parameters include loading, and environmental factors such as temperature, moisture, vacuum and electromagnetic radiation. Specific research in durability should focus on metallic alloys and super-alloys and active and passive cooling techniques for high temperature airframe and engine applications, advanced composite materials using polymeric resins, ceramic or metallic matrices, and solid rocket propellants.

4.1.2 Dynamics

The dynamics of aerospace vehicles and structural components underlie performance, stability and safety considerations during design, qualification and operations. The persistence of vibration (following excitation by steady or transient disturbances) and the potential for growth or decay of the deformations and stresses, must be understood and be predictable. Current dynamic prediction methods are largely based on assumption of linear structural behavior, rendering them of limited applicability to situations involving structural non-linearities. Such situations are becoming more prevalent as new materials with time-dependence and rate sensitive properties, such as advanced composites and viscoelastic materials, are introduced into vehicles as primary structure or vibration control devices; or as active control concepts and devices are used to improve energy efficiency and to moderate vehicle response in gust and impulsive environments. Needed research involves the development of analytical prediction methods and experimental methods, and the application of these methods to specific configurations and operational environments to further elucidate the time dependent structural response phenomena. The analytical methods development needs to address the various sources of non-linearity: material inelasticity and anisotropy,

large deformations, frictional resistance, and structural interactions with mechanical subsystems, etc. Applications research of interest to the Air Force includes active control and aeroelastically tailored configurations, high speed projectile impact and penetration, unprepared field take-off and landing, weapons delivery/airframe interactions, dynamics of large space structures and vibration control of electro-optical systems.

4.1.3 Aeroelasticity

As the performance spectrum for aerospace vehicles continues to expand, the need for methods to analytically and computationally determine the coupling of structural deformation with aerodynamic unsteady loads, in a fully three dimensional manner, grows in importance. In the transonic speed regime the presence of shocks in the flow field creates complex interactions with the flight vehicle structure that are not readily predictable with current analysis tools. Likewise, the unsteady flow fields of aircraft carrying stores and their effects on the vehicle flutter modes are not readily or economically predictable. Research needed to remove these limitations should include experiments to identify and understand the mechanisms underlying nonlinear flow effects, to mathematically model them, and to effectively connect them with structural models which account for large deformation nonlinear behavior. The combined models would provide the basis for other research activities to investigate the flight stability characteristics of vehicles and to develop active and passive techniques for controlling flutter and aeroelastic internal loads. In addition, research is needed in aeroservoelasticity, a discipline that involves the integration of structures, aerodynamics and controls techniques. Aeroservoelasticity involves the measurement of unwanted aircraft flexible motions, the processing of this signal by a high gain control system with advance phase characteristics, and the movement of a control surface producing aerodynamic loads such that the interaction with the structure counteracts the unwanted motions. Investigations are needed to develop from first principles the integrated governing equations of motion with a goal of obtaining time domain design, analysis, and simulation techniques using nonlinear structural and aerodynamic theories.

4.1.4 Structural Synthesis/Optimization

The design of lightweight structures with stringent performance requirements is the primary motivation for research in structural optimization. The problems associated with relative minima, variable stress constraints, multiple constraints and modal coalescence are some of the unresolved issues impeding efficient implementation of optimization algorithms. Stresses, displacements, frequencies, flutter velocities and dynamic response are the primary constraints in design optimization. Weight, cost and stiffness are generally the objective functions to be optimized. The loading environment can include static, dynamic, aeroelastic, and thermal components. Accurate modeling of stiffness, mass and damping properties is necessary for effective optimization. The new developments in organic and metal matrix composites present excellent opportunities for tailoring structures to specific performance requirements. Such tailoring of complex structures can only be carried out with the aid of reliable optimization methods. The dynamics and control of large flexible space structures can present a number of difficulties for the development of optimization methods. A real need exists for automated techniques which can realistically and accurately incorporate the many

(e.g., fatigue, fracture, thermal stress, stability, imperfection sensitivity, aeroelastic effects, structural tailoring, active control) requirements which a successful vehicle must meet. A formal optimization capability for new structural configurations of advanced materials, incorporating costs, strength, weight, aeroelasticity and fracture mechanics constraints, is needed.

4.1.5 Analytical Methods

Analytical methods which are the foundation of all scientific endeavors in applied mechanics represent the application of mathematical principles to the description and quantification of the physical laws that govern the behavior of materials in all environments or usage. Research in analytical methods is necessary to capitalize on advancements in mathematical formulation, computational techniques and tools, and fundamental understanding of the physical laws. Areas of needed research include formulation of constitutive relations, development of variational principles of mechanics and their application to continuum or finite element idealization of structural components, and adaptation of numerical methods to the solution of structural equations. Constitutive modeling needs are particularly critical for anisotropic, inelastic, temperature-dependent and rate-sensitive materials with physical damage (micro-cracks and voids).

4.1.6 Multidisciplinary Design

The development of aerospace vehicles is a complex process involving the configuring and sizing of subsystems to meet many and often conflicting requirements and encompasses many technical disciplines. While each discipline concerns itself with optimizing specific aspects of the subsystem to appropriate elements of the design requirements, interaction among them is necessary for overall system performance optimization. Research in multidisciplinary design is therefore aimed at improving the optimization process and product reliability at a systems level. Areas of research needed in optimization include development of generalized procedures that are applicable across many disciplines; formulation of disciplinary considerations in terms of global optimization criteria, logical sequencing of the various disciplinary analyses, and the identification and facilitation of data exchanges among the disciplines. Research needed in reliability includes construction of statistical models for both system and subsystem or component reliability, development of nonparametric regression for survivability models to determine sensitivity of system survival to system variables, and the development of improved simulation and test techniques.

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SCOPE

The Fluid Mechanics subarea encompasses research to illuminate the behavior and controlling mechanisms of complex flow fields associated with aerospace vehicles having configurations and operating in flight regimes of importance to the Air Force. The overall objective is to provide the foundation of basic knowledge essential for the successful development of advanced vehicles and systems capable of satisfying future Air Force mission requirements. To achieve this goal, research should provide both physical understanding of key flow phenomena and modeling capability based on that understanding, to devise advanced theoretical analysis techniques, and to originate new concepts which have promise for expanding current aerodynamic performance boundaries.

Specific areas in which research is required include the following: determination of the role of turbulence structure in boundary layers and free shear layers; improved modeling for strongly interacting viscous flows; advancements in the efficiency, stability and accuracy of numerical methods for three-dimensional viscous and nonlinear viscous flows; determination of the qualitative and quantitative features of separated and attached unsteady flows; determination of real gas effects and transition mechanisms in hypersonic flows; improved prediction capability and innovative thrust augmentation concepts for powered lift aerodynamics; determination of the factors governing the stability of high speed boundary layers; surface roughness effects on turbulent boundary layer characteristics; determination of the vorticity creation in high speed flows; and the definition of those factors which affect the interaction between a supersonic stream and an impinging high energy source.

4.2.1 Inviscid Aerodynamics

Advanced theoretical methods are needed for the analysis of inviscid flows in all flight regimes. Advancements are required in analytical and numerical procedures for the analysis of three-dimensional flow fields about complex shapes. To evolve such methods to engineering design and analysis tools, optimum computational grids and reduction of computer time and storage requirements are needed. Included are analytical methods for nonlinear transonic, supersonic and hypersonic flows. Correct modeling of shock location and strength as well as weak viscous interaction effects are important problem areas. Methods are sought which would be applicable to complex configurations typical of cruise vehicles and to multiple interfering bodies with complex shock wave patterns.

4.2.2 Boundary Layers in High Speed Flows

The accurate prediction of surface heat transfer rates and shear stress is essential to the definition of the operational envelope of high Mach number flight vehicles and reentry vehicles. The operational envelope is constrained by the thermal protection system, stability characteristics and control system effectiveness which are strongly influenced by viscous phenomena. The ability to predict transition from laminar to turbulent flow affects both heat transfer

and force and moment characteristics for such vehicles. Important research issues include the determination of the roles of nose tip bluntness, angle of incidence and surface roughness on flow stability. Surface roughness affects heat transfer, surface shear and control effectiveness. Critical elements to be addressed are roughness height, roughness distribution and adverse pressure gradients. To improve turbulence models, measurements of statistical turbulence properties are needed for boundary layers over rough surfaces and subjected to adverse pressure gradients.

4.2.3 Powered Lift Aerodynamics

Aerodynamic design capabilities are inadequate to develop flight vehicles which can operate at very low speeds during take-off and landing but which do not suffer serious compromise in overall mission effectiveness. Research areas which address this deficiency include multiple exhaust jet interactions, jet interactions, jet induced aerodynamic effects in external flow fields and the energy exchange process in thrust augmenting devices. Methods are required for predicting the effects of energetic, turbulent jets near surfaces or arbitrary shape and orientation and turbulent jets in cross flows. Uncertainties exist in turbulence modeling for different regions of these flow fields such as in fountains and at jet impact locations. Techniques must be advanced for obtaining higher order, embedded flow field solutions. Also, research is needed to understand and thereby avoid errors due to scaling effects in the use of experimental data obtained with small test models. In the area of thrust augmentation, key research issues involve methods to accelerate the mixing process of multiple jets within a shroud. In particular, information is required to quantify the controlling parameters, to identify the role of large scale vortical structures, and to examine the possibility of energy exchange between streams via time dependent pressure forces.

4.2.4 Unsteady Flows

Recent advances in flexible structures and active controls technologies suggest an emerging capability to manage local flow field characteristics associated with flight vehicles which are inherently unsteady. An understanding of unsteady flow elements associated with large amplitude wing motions is needed to assess potential benefits and limitations which impact the development of future highly maneuverable aircraft. An evaluation of the aerodynamics effects (including thrust loading) coupled with increased knowledge of unsteady boundary layer behavior associated with these complex unsteady flows is required. Research in complex unsteady separated flows (e.g., dynamic stall) may lead to new concepts for enhanced vehicle maneuverability in which controlled separation vortices are employed for lift augmentation to expand the stall-limited portion of the flight envelope. Knowledge of the effects of three-dimensionality, compressibility and motion time history in these flows is extremely limited at this time. The general class of flows which involve nonstationary boundary or reference flow conditions may find useful application but remain largely unexplored. Another class of unsteady flows requiring study exhibit self excited oscillations which result from time dependent viscous interactions. These flows can seriously alter the aerodynamic performance and control characteristics of flight vehicles, and the capability to evaluate the sensitivity of a given configuration to these effects is needed. Research on non-linear flight mechanics incorporating unsteady flow effects will lead to enhanced flight vehicle maneuverability.

4.2.5 Structure of Turbulence in Shear Layers

Flight vehicle operations occur in an environment in which associated boundary and free shear layers are usually turbulent. In order to understand the properties of boundary layers, wakes, jets, and free shear layers, research is required on the fundamental processes which lead to and sustain turbulence in these flows. Recent recognition of the importance of deterministic, coherent structures in turbulent shear flow has suggested new approaches to the passive and active control of transport processes. Increased knowledge of the role of these structures and their interactions in turbulent boundary layers may lead to new methods for light vehicle drag reduction while an understanding of their behavior in jet flows and other free shear layers should result in improved fluid mixing techniques. Research to identify and characterize these structures should be complemented by the development of an accurate prediction methodology. Phenomenological turbulence models which incorporate known structural characteristics are likely to overcome a significant barrier to the accurate numerical simulation of fluid flows. New concepts for interactive flow control strategies are needed for optimal control of turbulence in bounded and free shear flows. Knowledge of the optical properties of turbulent shear flows is needed for advanced applications in high power lasers and optical imaging systems.

4.2.6 Stores Separation

Work is needed to improve techniques for predicting the interference effects for external pylons and stores to assure safe store separation over the entire flight envelope. An understanding of the interaction between structural dynamics and aerodynamics in all flight conditions is essential.

4.2.7 Complex Viscous and Separated Flows

The types of flow included in this area are those in which regions where viscous effects are significant cannot be decoupled easily from an essentially inviscid outer flow. Phenomena arising from this strong viscous-inviscid interaction can have significant, and usually adverse, impact on the aerodynamic performance of flight vehicles. Research is needed to advance methods for modeling and predicting turbulent, three-dimensional flows having thick boundary regions in corners and near edges, and experiencing large flow separations induced by shock waves and other large adverse pressure gradients. For three-dimensional separated flows, uncertainties exist in the flow field structure and consequently in the applicable scaling laws. The proper characterization of turbulence structure in high pressure gradient regions is also an area of concern. Experimental investigations are required to understand the flow characteristics associated with the subsonic leading edge condition of a sharp delta wing traveling at supersonic Mach numbers. Research is needed to study the interaction between reaction control system jet flow and the flow on the leeside of hypersonic vehicles at angle of attack in low density flow fields.

4.2.8 Numerical Methods in Fluid Dynamics

With the advent of high speed digital computers, numerical solutions of the nonlinear partial differential equations of fluid dynamics are feasible for

increasingly complex cases. These numerical methods comprise a powerful tool for investigating the physical features of complicated flow fields, in the sense of "numerical" experiments, while also offering the possibility of greatly enhanced design and analysis capability for flight vehicle development. To achieve this potential, research is needed to develop efficient, stable, and accurate algorithms for solution of various forms of the Navier-Stokes equations with emphasis on three-dimensional flows. Computational speed must be improved by devising methods for accelerating solution procedures, such as through exploitation of advances in computer architecture. A critical issue for efficient and accurate numerical solutions for flows with complex three-dimensional boundaries is the generation of the computational grid. Techniques are needed for automatically generating body fitted grids which concentrate grid lines in high gradient regions of the flow, and ultimately allow the grid to evolve as the solution proceeds.

4.2.9 Hypersonic Flows

The hypersonic flight regime ranges from continuum to free molecular flow in a high temperature environment where real gas effects interact strongly with fundamental fluid dynamical phenomena. This regime imposes severe heat management problems and requires management and control of fluid mixing processes for supersonic combustion. Successful development of new technologies for hypersonic flight will require basic research aimed at the development of new concepts for supersonic mixing, research on the basic mechanisms of transition to turbulence in hypersonic boundary layers and a more complete understanding of the constraints imposed by real gas effects. Numerical prediction methods are needed which incorporate nonequilibrium gas chemistry, including the effects of wall catalysis. Modelling techniques for strong, fully three-dimensional viscous/inviscid interactions are required to provide predictive capability for shock wave/boundary layer interactions. Active flow control strategies may be required to achieve adequate management of heat transfer, aerodynamic loading and flow separation.

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SCOPE

The flight control research subarea concerns the development of methodology and techniques for controlling the motion of aircraft, spacecraft, and missiles. The required research includes efforts in electronics, aerodynamics, and mathematics to develop technology that serves as a basis for flight control system design. Specific areas of concern include stability and control parameter prediction, flight control system theory, display concepts and theory, and the analysis of controller/aircraft interactions. The design of control systems for piloted aircraft should permit more flexible operation with new reconfigurable aerodynamic surfaces and controls. The resulting aircraft should have enhanced maneuverability, improved structural load distribution, and better handling and ride qualities. The man/machine interface should be designed to enhance system performance characteristics through best use of human capabilities. Initial system design can be improved using modern control theory analytic synthesis techniques.

4.3.1 Pilot Interface

The dynamic interaction between the human pilot and aircraft control system includes internal processing and decision making, as well as discrete and continuous control inputs. Adequate mathematical models of these dynamic interactions are needed in all piloted system design studies and developments to insure flight safety and promote aircraft reliability, as well as to optimize the flying qualities and response characteristics of the piloted system. Current mathematical models require extensions to permit analytic consideration and realistic flying tasks characterized by large amplitude motions with time-varying or nonlinear dynamic behavior. New models formulated for engineering analysis and design are needed that encompass human performance, workload and internal processing.

4.3.2 Controlled Vehicle Dynamics

The introduction of air vehicles with expanded capabilities necessitates additional basic research to understand and predict aerodynamic flow properties, and the resultant vehicle dynamic characteristics, during large amplitude motions. Particular emphasis is needed at the extremes of vehicle motion, as manifested in both velocity and angle of attack, for potential application to manned and unmanned air vehicles. Unsteady and separated flow effects are of prime importance under these conditions. The need also exists for better modeling and prediction methods to describe structural dynamic interactions in view of the trend toward more flexible structural design in conjunction with the increased aerodynamic loads imposed by large motions. The above needs dictate a research emphasis on nonlinear modeling and analysis theory, distributed parameter systems, parameter identification methods and conceptual analysis and prediction techniques that consider the dynamic interactions of the atmosphere, the vehicle and, where applicable, the human pilot.

4.3.3 Load Alleviation

In the past, aircraft retirement was almost always governed by system obsolescence. For modern systems, retirement age will more likely be determined by uncertainties in airworthiness as a result of structural fatigue with the expensive alternative of major airframe refitting. Increased performance demands have necessitated and will continue to require reduced structural margins. Active gust alleviation systems have clearly demonstrated the fact that fatigue life can be extended by exploiting modern control concepts. Formal methods are required for analysis and control synthesis in the preliminary design stage. New methods are needed to predict structural mode characteristics, and to understand how they interact with aircraft stability, control, and handling qualities. Better definition of design criteria is needed.

4.3.4 Integrated Design

To achieve optimum air vehicle performance over an expanded flight envelope requires integration of aerodynamic properties, vehicle dynamics and human pilot characteristics into a total controlled dynamic system. To reach this goal, research is needed in the area of large-dimension system modeling and analysis, and control analysis techniques that consider essential nonlinearities. Research is also needed to insure that conceptual control strategies for such large-dimension systems can be implemented in real time. One element of this research includes developing techniques to sense, identify or synthesize the large number of parameters essential for controlling large-dimension systems. Real-time adaptive control theory should be extended where needed to account for unmodeled or unanticipated variations in the large-dimension system dynamics. Finally, a systematic theory is needed to achieve full consideration of these various elements during preliminary design analysis.

4.3.5 Flexible Structures

As a result of the accelerated trend toward lightweight vehicles, structural flexing has become a more significant aspect of the flight control problem. Not only has the flexibility increased, but also the flexible modes are closer in frequency to the flight system response modes, primarily because performance requirements force faster response, driving system modes to higher frequency. Under these circumstances, flexure modes once considered negligible are now a substantial aspect of the control problem, and have been treated as such for some time. Techniques for accounting for these modes have always involved coarse lumped-parameter approximations. A reasonably accurate model for a flexible system would contain partial differential equations. It is important that the inaccuracies incurred by lumped-parameter approximations be analyzed and understood. Extensive effort is required in the area of distributed parameter analysis and control before this understanding will be realized.

4.3.6 Weapon Delivery Accuracy

Increased weapon delivery accuracy would make an important contribution to the effectiveness of the Air Force inventory of aircraft, while at the same time reducing aircraft vulnerability for any assigned mission. Needed are new sensor concepts, new display techniques, and new methods for control synthesis. Investigations are required to exploit newly discovered physical phenomena for use in sensors which detect, accurately locate, and designate targets. To process and properly utilize this information requires basic studies to develop simplified methods for accomplishing intelligent filtering. More immediately, theoretical studies are necessary to find more efficient, less computationally complex ways for controlling analog systems with digital computers.

4.3.7 Flight Control Performance Criteria

The use of digital computers for control, data processing and display generation functions in the total pilot-vehicle or unmanned dynamic system results in a hybrid system. Both analysis methods and the criteria used to judge flight control system performance require modifications and extensions for such systems. Research will develop and extend the capability of high performance multivariable digital control systems to reject external disturbances and to track multiple command inputs while operating in real time. The effect of dramatically reduced sample rates on flight control system performance should be explored and criteria established for practical bounds because of the significant impact of sample rates on the complexity of computational requirements. Emphasis will be placed on evolving analytical synthesis or design theory for multivariable hybrid systems to incorporate specified stability and response characteristics.

4.3.8 Flight Dynamics Systems

Characteristically, present vehicle control systems are designed relying heavily on classical analysis techniques which are limited in capability for the design of multiloop feedback systems, and simulation which is costly to operate and optimize. Clearly, work is required in the development of advanced control theory and technology and their application to advanced vehicles and control system problems. The development of suboptimal control theory for precise terminal control is of particular importance. Emphasis is also needed on the development of computer aided design techniques for aircraft flight dynamics systems that consider the integration of various control functions and the trade-offs involved during preliminary design.

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PROPULSION AND POWER

TECHNICAL AREA

PROPULSION AND POWER

INTRODUCTION

Future Air Force missions require higher performance, increased reliability and lower life cycle cost for missile propulsion, aircraft propulsion and power systems. This emphasizes the need for pursuing a strong and viable program in advanced propulsion and aerospace power technologies.

Achievements in the field of Rocket Propulsion utilizing composite materials, high energy propellant ingredients and advanced energy management techniques promise sharp increases in performance, approximately double. However, to maintain that momentum in the coming decade, it is imperative to maintain a broad base of research. The work responding to future research objectives will provide the knowledge that new systems can draw on to solve exploratory and advanced development problems. These efforts may lead to a revolutionary or breakthrough technology that changes the traditional concepts of rocket propulsion.

Continuing research programs related to air-breathing propulsion components, control, instrumentation, diagnostics, and overall propulsion systems integration is the foundation for continuing progress in advanced air-breathing propulsion system development. Investigation in technologies related to fuels and lubricants, fires and explosive protection and propulsion system survivability are required to adequately support the overall technical base needed for the evolution and revolution of future generations of air-breathing, propulsion systems. The revolution in airbreathing propulsion will come from the High Performance Turbine Engine Technologies (HPTET) and Combined Cycle Initiatives.

Air Force requirements for efficient, reliable, survivable, and lightweight aerospace power systems over a broad spectrum of terrestrial, aircraft, and space system applications place continuing demands on the need for strong research in power generation, distribution, control, and storage as well as new, innovative ideas in the area of energy conversion. New technology must produce aerospace power systems which possess greater efficiencies, more durable components for longer operational service life and must be able to survive increased hazards posed by the more sophisticated electronics countermeasures and high energy weapon effects envisioned in projected conflict scenarios. Space Power research will receive increasing attention to assure the Air Force has the technology base for future spacecraft.

See also the following two Project Forecast II initiatives (subarea 9.1):

PT-01 High Energy Density Propellants investigates the existence and stability of excited state compounds and species as potential propellants.

PT-05 Space Power explores both non-nuclear and nuclear space power technologies capable of providing 10-100 kilowatts electric power.

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SCOPE

The Rocket Propulsion Research Objective encompasses mid-term and long-term requirements for research which supports the development of primary and secondary rocket propulsion, electric propulsion and chemically derived auxiliary power. Goals are stated in terms of improved performance, reliability and durability of Air Force rockets for a broad range of mission applications as related to four AFRPL Major Thrusts, which are as follows:

- a. Ballistic Missile Propulsion
- b. Air Launched Missile Propulsion
- c. Space Propulsion.
- d. Multiple Application Technology

Specific provisions are included for research directed toward exploiting scientific opportunities which cannot be related to particular mission areas at this time.

5.1.1 Structural Mechanics

Failure Theory and Criteria: There are imperfections existing in solid propellants. These imperfections may be produced during the manufacturing and/or fabrication process of the grain. In analyzing the strength of a solid propellant, the localized imperfection may be idealized as a crack in the material. Besides the idealized crack, large cracks can also develop in the solid propellant grain during storage, firing, etc. However, the development of cracks in the propellant grain does not necessarily mean that the service life of the motor is terminated. Past experience indicates that rocket motors with structural flaws, such as bore cracking or unbonds, have been static fired successfully without leading to catastrophic or unacceptable ballistic performance conditions. This implies that a cracked propellant grain is still usable as long as the crack does not affect the ballistic performance requirements. Therefore, to determine the ultimate strength or the ultimate service life of rocket motors, studies should be conducted to determine the significance of flaw types, size, and rate of growth. In order to conduct these studies, a detailed knowledge of crack growth behavior in solid propellant is imperative.

The interdependence of modulus, Poisson's ratio, and specimen geometry on stress intensity factor need to be investigated. Crack growth data under constant strain rate and constant load conditions need to be generated to determine the relationship with stress intensity factors as a function of time. The existing theories (e.g., Schapery, Knauss, etc) describing the relationship between crack growth rate and stress intensity factor should serve as a baseline.

Constitutive Models: Failure and response mechanisms of non-linear, visco-elastic, highly loaded solid propellants remain elusive to finite solutions. Constitutive theory and analytical models need to be developed which accurately describe the composite material behavior. Of specific concern is the cumulative damage, material response and failure behavior of solid propellants under monotonically increasing loading and cyclic loading.

Mechanical Properties: A critical problem in solid propellant service life programs is the lack of adequate models for aging. A requirement exists for a theoretical model to describe this chemistry-chemical structure-mechanical property interrelationship. Knowledge is required of the coupling between the chemical rate constants and the mechanical relaxation processes which dominate mechanical response and rupture, particularly at the bonded interfaces.

Cases and Nozzles:

Materials: Specialized composites continue to find broader application in nozzles and cases for solid rocket propulsion motor applications. Specific research is needed to define failure response for carbon-carbon structures employed in high temperature exit cones and throat pieces for rocket nozzles. Research into the response of thermally degrading boundary interfaces between these nozzle pieces is also required. For cases, response of prestressed, crazed kevlar composites, quasi-creep response, migration of release agents, and mixed resin-fiber research is required.

Thermal Protection: Research is required in several areas of the thermal behavior of composites employed in solid rocket nozzles and cases. For nozzles, the active surface areas of carbon-carbon composites and their interaction with selected rocket exhaust species needs to be evaluated. Limited results indicate that variations in the areas and their corresponding activation energies occur between the different carbon-carbon composite finished products. Such activation energy differences are anticipated to impact carbon matrix state formation in the various forms of composite densification methods employed. Thermal cure for mixed resin and mixed fiber composites also requires continued research.

Liquid rocket engine turbines are limited in their operating temperature capability and life by the elevated temperature strength and the thermal cycle capabilities of the superalloys used for turbine blades. Ceramics such as silicon nitride are intriguing because of their high temperature capabilities but suffer from susceptibility to thermal shock. This problem is particularly severe in rocket engines because of the rapid start transients and probable exposure of the turbine blades to cryogenic propellants before start and at shutdown. Fundamental material development efforts are needed to improve the thermal shock capability of this class of material.

Concepts: The use of composite structures in solid rocket nozzles establishes design options not previously available. The orientation and type of fiber and fabric reinforcements are open to design creativity and material capability. Research is required to explore the design horizons. Critical needs exist now for transition pieces around concentrated load points and part connections. Analysis techniques which provide for load distribution control in edge transition pieces with mixed matrix and reinforcement constructions need research.

Composite material and fabrication concepts which take advantage of both expanded design horizons and energy efficient construction techniques need research. The carbon-carbon composite structures used in rocket nozzle cones and throat components are processed with high temperature, high energy intensive methods. Research into improved techniques could reduce time and energy consumption while offering the potential of improved products. For motor cases, research into the order of fabrication steps, curing techniques, and holographic inspection offers both the potential for improvement of current products and a significant risk reduction in future system development.

Nondestructive Evaluation: During the life of solid rocket motors, micro-events generally occur which reduce the strength and life of the structures. These events are called damage. Damage in composite materials; particulate and fiber-reinforced, consists of complex and interactive damage modes which may be produced either during manufacturing processes or by service loads. Throughout the loading history, the progressive development and interaction of various damage modes changes the state of the material and the response of the structure. Therefore, in order to use these materials effectively in engineering design, one needs to understand (1) how these materials behave under load, (2) the effects of initial imperfections on the final properties, (3) the nature of damage development under load, (4) the sequence of damage events that lead to the final fracture, and (5) the effect of damage on the remaining strength and life of the material.

Nondestructive testing (NDT) and evaluation of composite materials have received increasing attention in recent years to evaluate and predict the mechanical properties of the materials. Because of the complexity of the damage state conventional NDT methods are unable to provide a useful parameter to characterize the damage. Therefore, there is a strong need to develop NDT techniques which are capable of yielding parameters which are indicative of the damage state in the composite materials.

5.1.2 Exhaust Plumes

Spectral and Optical Characteristics: Non-intrusive diagnostic techniques are needed to measure the properties of many different rocket flow systems. Applications include optical measurements of nozzle-exit and plume flow field properties for verification of fluid mechanics models such as NIM III, and Jet Plume Flowfield and Monte Carlo codes, which are the principal methods used in the reliability of plume radiation predictions; measurements of rocket exhaust properties to assist in the interpretation of performance and flow measurements of flowfield properties in combustion processes; and measurements of primary and secondary plume characteristics and how these characteristics are influenced by various propellant formulations.

Two types of data are required in order to calculate the plume infrared spectra and transmission through the atmosphere. First, detailed line data (e.g., AFGL line atlas) are needed to perform tedious line-by-line calculations and, secondly band model parameters (e.g., NASA Handbook) are needed for rapid prediction capabilities. These data are needed in order to determine optimum bandpasses for various sensors to be used for detection and tracking.

The ultraviolet spectral region may become of greater interest to the Air Force. In order to consider this wavelength region, it is necessary to model the ultraviolet plume emissions. It is well known that rocket exhaust plumes radiate in this region, but the mechanism responsible for production of this radiation is not firmly identified.

Gas Dynamic Interactions: There are several applications of this research: development of smokeless propellant technology and prediction of surface degradation caused by impingement of condensates from satellite thruster plumes. In all of these applications it is necessary to predict the onset (i.e., nucleation characteristics) and extent (i.e., growth characteristics and size/spatial distributions) of condensation, for which the kinetics are important.

Plume signature characteristics are of interest for a variety of missile systems. In many practical situations, particularly for ballistic missiles, multiple nozzles are employed. The interaction of the separate exhaust plumes and subsequent effect on the plume flow field properties are extremely difficult to predict, and to date no straightforward and efficient method has been developed. Currently, the exhaust plume is treated as a single equivalent plume, a situation which is totally inadequate for some problems.

The base flow region of a missile in powered flight represents one of the most challenging problems in fluid dynamics. Separated flow, turbulent mixing phenomena, non-equilibrium chemical kinetics, strong pressure interactions, compressibility effects, mixed recirculating flows and unsteadiness are all potentially present in the base region of missiles and aircraft. Improved understanding of the basic physical processes and better analytical approaches to predict base flow behavior is currently a strongly developing research objective.

The calculation of exhaust plume properties requires understanding and modeling of the fluid mechanics of turbulent mixing and combustion at high flow velocities. Rocket motors exhaust at high supersonic velocities into a free stream of comparable mach number. Since conventional missile propulsion systems operate quite fuel rich and the afterburning of this fuel creates many of the problems with which vehicle designers must deal, understanding turbulent combustion at these conditions is an important Air Force research objective.

5.1.3 Solid Propellant and Energetic Materials

Oxidizers: Air Force mission requirements for greater payloads, greater flight distances, quicker delivery times, longer stand-by situations and smaller overall systems tax the capabilities of existing rocket oxidizers.

To meet these Air Force needs in the space and ballistic propulsion area, liquid propellants offer certain advantage over the solid counterparts such as throttability. Today's state-of-the-art storable oxidizers are N_2O_4 , ClF_3 , and ClF_5 . It is desirable to synthesize and characterize oxidizers having more energy than the above yet having high density and storability under nominal pressure and temperature conditions. Low-cost access to space is another important issue. Ammonium nitrate oxidizers are very low cost and would have application to many systems including class 1.3 minimum smoke and clean propellants. Research is needed to investigate the optimum way to phase stabilize ammonium nitrate and to improve its combustion efficiency.

Binders and Plasticizers: Research is needed on the synthesis of modified or new tough, cureable, high energy polymer binder candidates for smokeless propellants, high solid loaded formulations and/or high performance hybrid fuels with vastly improved mechanical, physical, and chemical compatibility characteristics including a thermochemical stability $>200^\circ C$ and a glass transition temperature as low as $-55^\circ F$. Research is also needed on the synthesis of low-cost thermoplastic elastomers for use as solid propellant binders. Emphasis will be placed on improving processing and mechanical properties with the minimum amount of plasticization.

Propellant Systems and Processing: Research is needed on potentially new chemical syntheses designed to define specific new chemical synthetic transformation to improve overall synthetic routes to known candidate propellant ingredients, to produce new target compounds, and to provide on-going syntheses of novel model compounds required for investigations in complementary in-house chemical research programs.

Hazards: The polymeric binder systems employed in solid propellants require adequate stabilizers to protect them from various ingredients, contaminants and environments. Models which describe the chemical degradation mechanisms are required to develop effective antioxidant packages, metal deactivators and thermal stabilizers. The mechanism of concern is nitrate ester decomposition which results in NO gas generation which leads to high internal pressure and propellant fissuring.

5.1.4 Combustion and Reacting Flows

Performance and Efficiency: Current analytical methods cannot adequately account for all of the effects of motor geometry and operating conditions on delivered solid rocket performance. Due to either grain asymmetries, nozzle design, or thrust vector control, the flow in a solid rocket is usually three-dimensional. Accurate and economically feasible, analytical methods are needed to calculate the three-dimensional, two-phase flow in the grain cavity and rocket nozzle.

Metal Combustion: Metals, particularly aluminum, play an important role in the combustion of solid rocket propellants. In addition to providing increased performance over unmetallized propellant formulations, aluminum particles enhance combustion stability. A thorough understanding of the basic phenomena of aluminum particle burning in oxidizing environments associated with solid propellants of current interest is needed to enhance the predictability of future high performance solid propellant missile

systems and maximize combustion efficiency.

The effect of the gas flow field on the steady state burning rate of solid propellants remains unknown. Motor ballisticians are frequently unable to predict the pressure-time behavior of solid motors before actual full-scale testing is accomplished. The primary difficulty is an inability to predict burn rate augmentation due to high velocity gas flow.

Although empirical models for predicting erosive burning are available, adequate test techniques for obtaining laboratory data are not. Combustion modeling needs to be improved and the fundamental mechanisms which affect erosive burning identified.

Stability: Improved analytical methods are needed for predicting the stability behavior of solid motors and liquid engines. Currently available analyses have recognized deficiencies in the area of nozzle damping, acoustic erosivity, velocity coupling, distributed combustion, particle damping, structural damping and high velocity mean flow effects on acoustic modes. Liquid engine acoustic cavity design and injector spray field interactions continue to require increased fundamental understanding. Research is needed in all of the above areas to improve the overall stability prediction capability for motors. Also of interest is the triggering behavior of motors due to pulsing and the possibility of predicting this behavior by advanced non-linear theories. Comparison of predictions to measurements should be done whenever possible as a means to evaluate the validity of the theory.

Theoretical development is needed for both pressure and velocity coupled response functions. Work is expected to proceed with analytically coupling gas phase and solid phase processes and eventually eliminating the quasi steady state assumptions that have been made. The combustion response modeling at high frequencies (above 10,000Hz) is desirable because of experimental difficulties of these frequencies.

Hazards: Azide polymers are being found to be an excellent prepolymer for several propellant applications including tactical missiles and starter cartridges. Little is known about the decomposition of azide ingredients. An understanding of the decomposition of these compounds would allow for increased energy (ballistic and tactical applications), higher burn rates (smokeless propellants), cleaner combustion (gas generators), and the potential of a stop-start capability (space applications).

5.1.5 Propulsion Concepts

Solid Propellant: High energy polymers with vastly improved chemical compatibility, thermochemical stability, and hazards risk are required for smokeless propellants, high solids loaded formulations, and high specific impulse hybrid fuels. Different molecular structures in energetic binder precursors emphasize a wide spectrum of propellant trade-off characteristics like energy output, storage life, hazard risk, and formulation properties. Different classes of energetic polymers should be investigated to achieve wide-range propellant properties. Improving the combustion efficiency of low-cost propellant formulations using inexpensive ingredients such as ammonium nitrate should be investigated.

Gas Generator: On-off control of solid propellants is a desirable capability for many Air Force missions. Much research is needed in the fundamental nature of solid propellant burning and initiation criteria. Burn rate control can be controlled by chemical additives but only over a limited range and most certainly not to the demand on-off condition. Mechanical control can also be achieved via pintle nozzles but this adds a considerable weight penalty to the system.

Electric Propulsion

Magnetoplasmadynamic (MPD): MPD thrusters have potential for being simple, highly reliable and capable of meeting electric propulsion requirements from millipounds to pounds of thrust required on large space systems. However, a great deal of research and technology is necessary before the reliability, long life, and optimum performance of the various thruster concepts is determined. Two of the most critical areas for investigation are insulator and electrode erosion and mass flow-current limitations to performance.

In addition, reliable operation of the pulsed MPD thruster requires advancements in the state-of-the-art for millisecond pulse gas valves and megawatt electrical switches. These two requirements are not unique to MPD propulsion but apply across the board to gaseous fuel plasma propulsion systems. These areas should be addressed for both the pulsed and steady state MPD thruster.

Pulsed Plasma Thruster (PPT): Pulsed plasma using solid teflon propellant is a reliable and efficient propulsion system for meeting Air Force auxiliary propulsion requirements. However, no attempt has been made to improve mass utilization efficiency, i.e., the percentage of fuel that gets ionized. It is anticipated that improvement here could result in the thrust efficiency increasing by as much as a factor of two (from 25 percent to 50 percent) and plume back flow (neutrals) being significantly reduced (thereby reducing the contamination hazard to spacecraft).

Laser: The ability to perform ambitious space operations is strongly linked with high specific impulse propulsion systems. Laser propulsion offers the potential for escaping the specific impulse limitations of chemical rockets without falling into the very low thrust regime of electrical propulsion devices. Efficient ways are needed to couple laser energy into a working fluid without generating hardware-damaging plasmas or coupling instabilities. Beam entry will require high strength, refractory window materials. High efficiency, high power, closed cycle lasers are needed for operation in orbit, and very accurate pointing and tracking must be developed.

The transport of energy by beams of particles accelerated to relativistic velocities has been proposed for space application. The feasibility of adapting this concept to the remote powering of propulsion systems needs to be examined. Many of the concerns are the same as those investigated earlier in connection with laser propulsion - the generation and propagation of the beam and accurate pointing and tracking. Beyond this it is necessary to devise ways of capturing the energy at the propulsion device and converting it into thermal energy in the working fluid. Much theoretical work is needed on the spreading of the beam and its deflection by magnetic fields. Concepts for employing the ionosphere to interact with a charged beam and

confine it via magnetic pinch effects need to be studied; and the possibilities for steering the beam using error signals returned from the target need to be established.

Electromagnetic: Research is needed in hypersonic endo/exo-atmospheric flight of large launch packages. Control surfaces/devices/techniques need to be examined for feasibility of application at atmospheric velocities between 3 and 12 Km/sec. Stabilization techniques such as spin stabilization vs drag stabilization need to be explored. Research is required on the thermal impacts of extended hypersonic flight. Materials research is required to cope with the extreme environments.

Solar Thermal: Specific impulse significantly beyond the capability of chemical rockets is possible by heating hydrogen to temperatures of 2700°K and above, and such temperatures are accessible with highly concentrated sunlight. The major problems which require solution are concerned with the design of solar absorber-heat exchangers and solar concentrators. Research is needed on heat exchangers which can operate reliably at high temperature for extended periods and without reradiating excessive energy back to space. Advanced designs have been conceived with physical windows, particle bed and rotating bed heat exchangers. Window materials are needed which can transmit light over a broad wavelength range and which possess high strength and temperature capability. Research is needed on the heat transfer characteristics of rotating beds, both in fixed and fluidized modes at these high temperatures. Research is needed on very large, accurately formed, lightweight, stowable and space deployable concentrator mirrors.

Other Non-Conventional Propulsion: Space propulsion requirements for transporting large payloads to high orbits or planets require the expenditures of huge quantities of energy. To be able to deliver practical weights and sizes of payloads some means of propulsion other than that produced by conventional chemical reactions will be required. Theoretically, solar propulsion concepts could supply high performance but low thrust. What is needed is propulsion technology that provides high performance coupled with high thrust. Potential techniques that theoretically could provide the capability are nuclear fusion, free radicals, metastable atoms, and matter annihilation.

Antiproton Technology: Antimatter propulsion could provide 1200 to 20,000 seconds of Isp in high thrust vehicles. At 1200 seconds, this is two and a half times better than LOX/hydrogen, our best chemical system. And it is four times better than storable or solid propellants. Only a small improvement in the technology will up these numbers to a factor of ten or better, and missions not yet imagined will be possible. In operational terms, an "improved" antiproton rocket could produce a ten fold payload increase in the aerospace plane. More interesting scenarios include the capability to perform fighter-like maneuvers in orbit. That is, a space fighter could reverse orbit or do 90 degree plane changes while in orbit. Such maneuvers are impossible with chemical rockets. Mission time to such interesting locations as GEO, the moon, Mars, or the asteroids could be dramatically reduced. By way of comparison, the Apollo lunar mission launched a 7.5 million pound vehicle from earth and returned with a few thousand pounds. This represents a mass ratio of about 1000; or put another way, the payload was a tenth of a percent of the liftoff mass. Calculations show that the

maximum mass ratio needed for an antiproton rocket is 5. Thus the same lunar mission could be performed by a 500,000 pound launch vehicle returning a 100,000 pound payload.

Compact, Nuclear Propulsion: A new type of nuclear propulsion system uses a fixed bed of ceramic-encased uranium particles, through which a working fluid is passed. The heated fluid is then expanded through a nozzle to produce thrust. During operation, all fission product nuclei are contained within the particles. Propellants being considered are ammonia or hydrogen. A 660 lb reactor could product 10 K-lb thrust at 900 sec ISP. It would have a 22" diameter and contain about 11 lb of U235 and be totally reusable. Higher gas temperatures, enabled by materials advances, would allow performance increases up to 1700 sec ISP. The basic reactor could also be used in a continuous or burst power system.

High Energy Density Propellants: These propellants, if successfully developed, would provide a revolution in operational rocket propulsion. These new propellants would have a heat release which is an order of magnitude greater than the best chemical propellant combination in use today, namely oxygen/hydrogen. This high energy content can be translated into enabling technology for a small single stage to orbit rocket system (including horizontal take-off and landing) and some space missions (LEO to GEO and return with large payload fractions). The potential exists for application to combined cycle engines and explosives depending on the nature of any resultant propellants. The major thrust is to accelerate research in selected areas of atomic and molecular chemistry for non-conventional propulsion. Of particular interest is the electronic structure of atoms or molecules where large amounts of conventional chemical energy can be made available if the electrons are situated in other than their "normal" ground states. Many "impossible" electronic states in "normal" environments have been shown to exist. Improved theoretical models predict the existence of more high energy species with lifetimes on the order of milliseconds and longer.

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RESEARCH OBJECTIVES

Solid Propellant and
Energetic Materials

Structural Mechanics

Combustion and Reacting
Flow

Exhaust Plumes

Cases/Nozzles

Chemistry

Advanced Propulsion Concepts

Plasma Propulsion

Antiproton Physics

High Energy Density
Propellants

SCOPE

Research in airbreathing propulsion relates to a wide range of efforts to support development in aerospace vehicle and missile propulsion. It is interdisciplinary in that it requires research in physics, mathematics, chemistry, materials, aero and structural dynamics, and energy conversion. These disciplines must be interrelated (1) to enhance the understanding of the microscopic and macroscopic phenomena of the processes involved, (2) to formulate models to predict the phenomenological performance at realistic operating conditions, and (3) to synthesize new fuels, lubricants and other materials to increase the capability of the propulsion systems.

5.2.1 Fluid Dynamics and AerothermodynamicsInlets, Ducts, and Diffusers

Subsonic Inlets - Performance limitations of present inlets for use with subsonic aircraft are primarily identified with flight at two critical flight conditions, high (subsonic) Mach number cruise and high angle of attack at large engine flow rates (identified with engine-out operation at take-off conditions). Efficient computational methods are required if appropriate use is to be made of numerical methods for design. For the high Mach case, accurate internal flow description requires the use of finite difference techniques because of the difficulty of incorporating appropriate compressibility corrections in panel method codes. As a result, the development of algorithms leading to efficient and accurate representation of the boundary shapes, as well as calculation of the flow (including shock waves) is needed. Subsequent efficient incorporation of three-dimensional boundary layer solvers capable of handling separation and unsteady effects is desired.

Operation at low flight Mach number but high angle of attack introduces the possibility of occurrence of large separation and consequent large flow distortion at the engine plane. The development of computational capability to describe the important physical aspects of this class of flows is encouraged.

Supersonic Inlets

The principal loss mechanisms in supersonic inlets are identified with losses across shock waves, and with boundary layer (including shock-boundary layer) and boundary layer suction losses. Requirements exist for analytic prediction of such processes, including three dimensional and time dependent effects.

Compressor Fluid Dynamics

Computations of flowfields within compressors have proven useful for the description of many of the detailed flow interactions. However, internal flowfield calculation is not yet at a state where it can be relied upon to predict the onset of separation nor to quantitatively predict the losses. Efforts to attain such a capability, including the effects of the free stream turbulence and multiple blade row interactions, are to be encouraged. It is to be noted in this respect that the classical treatment of secondary flows by ignoring the (local) shear stresses in comparison to the pressure gradient contributions has been shown to be of only limited validity in the description of conditions in modern blade rows. Future analyses should incorporate appropriate viscous contributions.

Many compressor operational limitations involve the onset of fluid mechanical or structural instabilities. Thus, even though years of effort have been expended in the description of turbomachinery flutter, no fully reliable prediction technique is available to the designer. The field awaits a novel insightful approach.

Compression system instabilities in the form of rotating stall and surge remain the inevitable design limiting phenomena for gas turbine compressors. Insightful studies of such phenomena, as well as post-stall operation and stability are much needed.

Turbine Aerothermodynamics

Because of the very high aerodynamic loading and the requirement for cooling often found in turbines, the aerothermodynamics of turbine blade and vane rows remains extremely complex and only partially understood. Interactions of engineering importance arise because of the presence of three dimensional effects (e.g., secondary flows including the passage vortex, the horseshoe vortex, tip leakage), because of the presence of buoyancy effects and coriolis effects (internal and external behavior of cooling air) and because of the presence of time dependent effects. The latter effects include deterministic interactions such as the interaction of rotor and stator pressure fields and of "wake chopping," as well as the effects of high free stream and wake turbulence.

Even in regions where the boundary layer flows can be considered quasi two dimensional, the flow can be extremely complex, with the possibility of large free stream turbulence effects, large areas of transition, appearance of relaminarization (in the presence of large heat transfer and favorable pressure gradient) and presence of separated regions.

It is to be noted that analytical methods directed at the description of such a flow in any generality must have the capability of large variation in grid intensity. Note as an example requirement, that any scheme to include the substantial crossflows found in turbines must have sufficient resolution to resolve conditions within the turbulent sub-layer, where in fact, a substantial portion of the crossflow exists.

5.2.2 Structural Mechanics

Aeroelasticity

Research in aeroelasticity addresses the aeromechanical response of fan, compressor, and turbine blades and bladed disk assemblies. The aeromechanical response manifests itself either as flutter, a self-sustained excitation condition, or as forced vibratory motion in response to the aerodynamic forcing functions. While flutter occurs under a variety of aerodynamic conditions, the most troublesome and least understood flutter condition is that of stall flutter. The physical nature of the stall flutter phenomenon is understood only qualitatively, and prediction relies heavily on empirical knowledge. Experimental and analytical research is needed in order to accurately define the physics of the stall flutter phenomenon, develop improved models for response analyses, and provide reliable predictive capability.

The second manifestation of aeromechanical response is that of forced vibratory response of turbomachinery bladed disks. The lightweight, low aspect of ratio unshrouded airfoils currently being considered for future military turbine engines have many more resonant frequencies occurring in the engine operating range than past turbomachine airfoils. As such, it will no longer be possible to design around all blade resonances, but, rather, instances will exist where the turbine engine is operating at some blade resonances. In order to insure structural integrity under these conditions, in-depth knowledge of the aerodynamic forcing functions, damping, and blade resonant response characteristics are needed. This problem is further aggravated with the advent of complex inlet designs and their resulting complex distortion patterns.

Structural Dynamics

Available theories for predicting the structural vibratory modes of turbine engine blades are inadequate for configurations such as shrouded fan and compressor blades or unshrouded low aspect ratio blades. In the latter case, the modes shapes are highly complex in nature demanding a much more sophisticated modeling approach. The effects of the disk support structure and blade-to-blade mistuning must be included in analyses. Available vibration theories derived for isotropic materials are of little use for composite blades due to the inherent material characteristics of composite. New knowledge is needed as to the degree of damping/stiffening provided by the mid span shrouds of fan and compressor blades and blade disk coupling under various simulated engine operating conditions. Analytical techniques are needed which consider the effects of blade shape, twist, and composite lay-up procedures on the vibratory modes of the blade. Improved nondestructive dynamic testing techniques are needed.

The theories for predicting structural and rotor dynamic response to dynamic forces should address the effect of basic phenomena on component performance in the areas of rotor bearing stiffness and damping. Structural analysis methods which consider geometric and material nonlinearities are desired.

Structural Durability

Life prediction techniques which consider the effects of actual stresses on the life of turbine engine structural components such as fan, compressor, and turbine blades and disks are required. The reduction of material useful life due to fatigue and/or fracture stress levels imposed on the engine components when operating in the plastic range is currently unknown. Analytical and experimental techniques which can predict fatigue and fracture stress levels due to imposed aerodynamics, mechanical and thermally induced loads under specific engine operating conditions are needed. Development of cumulative damage material models which consider new material developments, as well as fatigue and fracture characteristics, are necessary.

5.2.3 Combustion and Reacting Flow

Combustion system research is an interdisciplinary effort which supports the development and refinement needs of airbreathing propulsion systems, including gas turbines and ramjets. Future aircraft and missiles will require propulsion engines capable of operating stably over wider ranges of altitude and flight speeds, and with greater fuel tolerance, faster response, maneuverability and control characteristics. Improved durability and reduced maintenance costs are required. Advanced supersonic combustion ramjets and composite engines will be required to provide propulsion capabilities for these systems.

Aerothermochemistry

The objective of aerothermochemical research is to predict the rate of energy release in turbulent, subsonic or supersonic, reacting particulate laden complex flow fields. Research will be conducted in three stages: determination of the dominant physical transport characteristics (are the turbulent flows of interest statistically stationary or controlled by discrete fluid structures?); investigation of the complex coupling mechanisms among turbulence chemical reactions, radiative heat transfer, particulate transport and compressibility; formulation of predictive computational models. Each of these stages will require closely coordinated theoretical and experimental programs employing advanced laser-based and other measurement techniques.

Instability

Combustion instability, which is inherent in high capacity combustors, is an exceedingly complex phenomena in airbreathing propulsion systems involving the interactions of many contributing processes. Research required includes the following specific areas:

- The nature, generation, and coupling of convective waves in combustng flows.
- The nature, analysis, measurement and coupling of vortex flows with the combustion process in turbulent reacting flows.
- The effects of the spatial location, dimensions and exothermicity of the combustion process on stability.
- Characteristics of the spray and atomization processes and their influence on the combustion instability problem.
- The general turbulent flame spreading problem, including the effects of swirl, radiation and multiphase flows.
- Response of inlet shock systems to incident acoustic waves and convective waves, and their coupling with the combustion system.

Fuel Sprays

The primary requirement in fuel injection is achieving control of the atomization process and the subsequent disperison of fuel droplets. Variations in the thermodynamic and fluid dynamic state of the surrounding gas must be taken into account. The anticipated use of lower volatility alternative fuels and slurries presents unique fluid transport problems both before and after atomization. Spray characterization has expanded beyond mean drop size representations and pattern to considerations of distributions of drop size and velocity and liquid non-uniformity. Conditions of optimum fuel ignition and combustion as functions of spray characteristics must be determined.

Fuel Chemistry

Propulsion and combustion efficiencies which are insensitive to variations in fuel chemistry will be required. The effects of fuel chemistry on combustor durability through soot formation is under investigation. Other adverse effects on combustion efficiency and exhaust emissions as functions of fuel chemistry will be studied with attention to the use of additives for controlling combustion. The unique properties of carbon and metal slurries will limit the use of these fuels until the transport, lubricity, thermal oxidative stability and combustion characteristics are better understood.

The effects of fuel chemical composition changes on combustion kinetics must be understood and kinetic rates accurately established. Simplified chemical kinetics models that accurately reflect fuel combustion in gas turbine and ramjet engines are needed as submodels for combustion models.

Experiments have been performed in flow reactors and open combustion systems such as flat flame burners at sub-atmospheric and/or atmospheric pressures. The basis for extrapolation of quantitative chemistry results to pressures representative of Air Force combustors has not been defined. Producing a capability to perform fuel chemistry research at conditions of elevated pressure and temperature is of great importance.

Diagnostics

Basic research goals related to the development and application of advanced diagnostic tools and techniques include the following:

- Isolation of critical soot formation and growth processes up to 1 MPa.
- High repetition rate (>4000 Hz) two dimensional quantitative (temperature, concentration, and velocity) visualization for turbulent combustion in laboratory combustors.
- Quantitative mapping of transient temperature, concentration, and velocity events in high performance combustors representative of operational engines.
- Sensing and diagnostic technique consistent with projected needs of adaptive control of operational engines.

Ignition and Combustion Enhancement

Photochemistry and catalysis offer the promise of significant improvements to combustion efficiency and stability in combustors and augmentors with present and future alternative fuels.

Future objectives must consider the application of photochemical techniques to practical combustion environments including supersonic combustion. Questions of durability, interferences by concentrations of particulates and gaseous absorption must be addressed.

Catalysis research must devise flameholder concepts which enhance combustion throughout the mixture of reactants while minimizing pressure losses. Chemical and structural durability must be demonstrated.

Further research on mechanical approaches for combustion enhancement will study mixture preparation. Areas of investigation include swirling flows, hypermixing techniques, heterogeneous processes and staged combustion.

5.2.4 Signature

Noise control techniques must ultimately be derived from basic research which is directed toward (1) an assessment of the relative importance of noise source; (2) theoretical/experimental evaluation of existing or advanced theories; (3) the development of a unified aero-acoustic theoretical model which includes a description of the intensity, directivity and spectrum of far field noise as a function of relevant operating parameters. Source generation in many areas cannot arbitrarily be separated from propagation and radiation effects (linear and nonlinear). Therefore, the problem must be approached from the context of generation, acoustic detection, propagation, radiation, and suppression. Research also is needed to control detectable thermal and particulate emissions.

5.2.5 Propulsion Controls

Control Theory

Advanced control configured vehicle technologies, such as thrust vectoring/reversing nozzles, horizontal and vertical canards, and high lift devices, are likely to characterize future aircraft weapons systems. Advanced nozzles and high lift devices rely directly on the interaction with the propulsion system, necessitating the development of integrated flight propulsion control systems. Research is needed in the area of developing control design methods for non-linear, large order, multi-dimensional, multi-rate systems such as aircraft, inlet, engine, and nozzle. Improvements will require extending linear control synthesis methods to include nonlinear system characterized by differing system bandwidths and differing performance objectives.

Systems Modeling

High fidelity, dynamic models of a complex system such as an advanced fighter aircraft are needed during several phases of a control system design. During the initial design phases, a detailed, non-linear model is needed to perform sensitivity analysis and open loop dynamic analysis to determine mode shapes and interactive effects of a highly coupled system. Control law design might rely on linearized, reduced order models derived from these same high order non-linear models. Research is needed in the area of developing highly accurate, computationally efficient mathematical models of a complete flight vehicle including aircraft, inlet, engine, and nozzle. These systems are characterized by aerodynamic, aeroelastic, and aerothermodynamic phenomena in addition to structural and energetic processes.

System Identification

The investigation of integrated flight/propulsion control laws will require the development of good, high fidelity, dynamic models of the airframe, inlet, engine and nozzle including significant interactive effects. Because the interactive effects are so complex and are configuration dependent, system dynamic characteristics are best found through experiment and wind tunnel tests as opposed to theoretical techniques. Research is needed in the area of developing non-linear system identification methods to estimate important system dynamics. This way accurate models of a specific vehicle configuration could be derived from wind tunnel test data.

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RESEARCH OBJECTIVES

AIRBREATHING PROPULSION
FLUID DYNAMICS & AEROTHERMODYNAMICS

STRUCTURAL MECHANICS

COMBUSTION AND REACTING FLOW

COMBUSTION AND REACTING FLOW

COMBUSTION AND REACTING FLOW

SIGNATURE

SIGNATURE

PROPULSION CONTROLS

TECHNICAL AREA COORDINATOR

SCOPE

This basic research objective is related to aerospace vehicle energy and power systems. Future military aircraft, missile, spacecraft electrical power, burst energy, and heat rejection requirements will require fundamental breakthroughs in solar, nuclear, and chemical energy source utilization. Major improvements in direct and dynamic energy conversion and energy storage device performance, pulse forming and power processing techniques, heat transport, and rejection methods are required to enable these advanced military aerospace vehicle missions.

5.3.1 Energy Sources

Research directed to improve utilization of solar, nuclear, and chemical energy sources is required. The ultimate feasibility and utility of space nuclear reactors will be paced by basic research contributions into the mechanisms and control of fuel swelling. Research addressing high temperature (2000°K), compact nuclear heat sources, fuel forms, fuel-clad compatibility, and core heat transfer phenomena is required. Chemically fueled directed energy missions require fundamental research solutions to reactant boil-off, supply rate, and thermal preconditioning problems.

5.3.2 Direct Energy Conversion

In the area of Direct Energy Conversion, research is needed in the development of photovoltaic conversion, thermionic energy conversion, magnetohydrodynamics, and advanced energy conversion concepts. Basic research addressing the present limits of photovoltaic conversion efficiency, radiation degradation, cost, and cell processing (metalization, antireflective coatings) is required. Specific areas that require research are: (1) transport property optimization of the various binary, ternary, and quaternary III-V materials, (2) effects of radiation damage in these materials, (3) reliable electrical contacting and survivability of such contact metalization to hostile environments, (4) multilayer antireflective coatings, and (5) ways to reduce the cost of fabricating such cells.

Fundamental research is required on thermionic energy conversion to reduce interelectrode losses and to further understand the pulsed mode of operation. Research needs for MHD generators are in the areas of nonequilibrium plasma behavior and electrode process mechanics, superconducting materials, and high-field superconducting magnets. Investigations are required to theoretically and experimentally analyze open cycle (10 to 100 MW) MHD generators to minimize plasma losses and gain understanding of the basic loss mechanisms. Also to achieve its full potential, the MHD generator needs materials for widely diverse temperature regimes including superconducting magnet materials, combustor liners, and instant-start electrode materials. Research on colloidal

suspension liquid propellants is needed as a hybrid between true liquid and solid propellant systems. Research on advanced high energy liquid MHD fuels is desirable. Additional knowledge is needed on the collision cross sections in seeded combustion plasmas and the resultant electrical conductivities. Research to increase the present boundaries of electrical conductivity at a given MHD operating temperature is needed. New approaches to operate the MHD converter at pulse times of 100 microseconds to several milliseconds are needed. Research is needed on losses (thermal and electrical), theoretical and experimental nonequilibrium conductivity and stability of advanced explosion generated plasmas, effects of magnetic Reynolds number, mechanisms of boundary layer and electrode processes.

Other advanced energy conversion techniques and phenomena such as pyroelectric, thermophotovoltaic, and ionic solid heat engines require fundamental investigation to further characterize their potential for power system applications.

5.3.3 Dynamic Energy Conversion

In the area of Dynamic Energy Conversion, research is needed in the development of multimegawatt gas generators for chemical turbines; high speed, high power permanent magnets; homopolar and superconducting generators; and high pressure (8000 psi) hydraulic systems. Research into the basic processes taking place in gas generator combustion chambers is needed to reduce the uncertainty which now accompanies gas generator design. Information is needed pertaining to the mixing, ignition, rates of heat release, flame speeds, and other processes and phenomena which take place in gas generator hardware in order to more fully understand detonation, acoustic coupling, "chugging," and other forms of instability which typically plague the design of new gas generators.

Three specific areas of electric dynamic energy conversion require research. These include: high speed permanent magnet generators, homopolar generators, and superconducting generators.

Permanent magnet generator performance can be increased by research activity in several areas. The first of these should attack the permanent magnet material in both energy product and temperature compensation. Work is also required for magnet temperature compensation for a high performance (greater than 29 MGOe) permanent magnet. Additional research is required for studying the dynamic interaction of homopolar DC generators with rail-gun-type loads.

For superconducting generators, research is required in techniques for fabricating small-diameter superconductive filaments (10 microns or less) in long lengths at reasonable current densities (5×10^4 amperes/cm² or greater) in ways that ensure current sharing among electrically independent filaments under fast pulses. High critical temperature superconductive materials should be developed in multifilament wires. Basic understanding of magnetic flux motion and associated losses in Type II superconductors is required. Knowledge of magnetic flux pinning sites and their influence is

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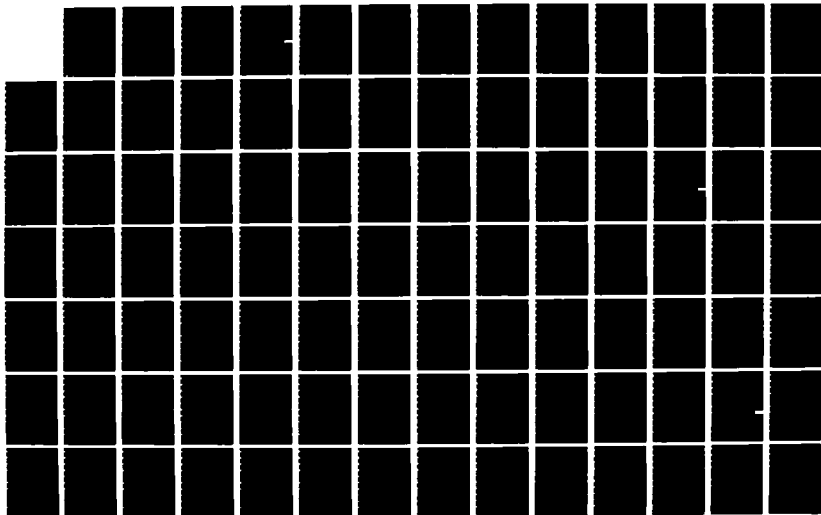
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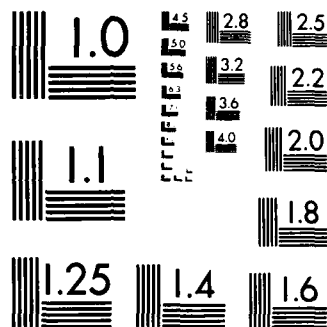
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losses is needed. Improved magnetization models of built superconductors and coil structures would clarify discrepancies between short sample and coil losses. The stabilizing effect of materials with flattened critical current versus temperature characteristics should be investigated. Stabilization coatings on superconductors which act as thermal delay lines and prevent temperature excursions during fast-rising transient heating should be investigated. Both internal and interfacial Kapitza boundary resistances should be evaluated for limitations in transient heat transfer to liquid helium.

Research is needed to investigate the basic mechanism of cavitation associated with high density fluid, high pressure (up to 8000 psi) hydraulic systems required for future high-performance aircraft.

5.3.4 Energy Storage and Conditioning

In the area of Energy Storage and Conditioning, research is needed to improve the performance of batteries, to develop inductive energy storage materials, improve the energy density of high power capacitors, and develop megawatt class repetitive switches. The performance of batteries is limited by the chemical compatibility, kinetics, energy density, and electrochemical potentials of various battery components. The research areas where the most substantial improvements are needed are in nonaqueous electrolytes, energetic electrode replating and kinetics, additive effects (either intentional or undesirable impurities), extended storage capability, and increased cycle life. Chemical and physical characterization of the thermal battery materials is needed to provide a consistent and predictable product that can be readily manufactured.

Research is needed to characterize superconducting, pure metal, and high conductivity intercalated graphite conductors as well as advanced composite structures for inductive energy storage. Transient losses in superconductors due to fast rising pulses must be understood and treated.

High energy/density discharge capacitors with energy densities of several hundred joules/pound, capable of operating at a few hundred pulses/seconds, are needed. Research is required to identify and/or develop dielectric systems (dielectric films and impregnants, solid dielectrics such as ceramics and liquid dielectrics) for capacitors having the energy density, energy capacity, voltage charge-discharge rate and long life.

Superconducting switches offer a method of switching high currents that is usually limited to single shots. Utilization of new superconducting materials and thermal stabilization systems may permit fast repeating pulses to be generated by inductors if the transient heating in the switch can be accommodated. Research is needed to overcome the present limits on the ability of semiconductor devices to accommodate large current transients, to block high voltages in the forward direction, and to operate with fast rise times in rapid pulse operation.

5.3.5 Thermal Management

Basic research solutions are needed for advanced spacecraft thermal management applications. Future military spacecraft will require major advances in heat transport, rejection, and thermal storage devices to accommodate these high power missions. Fundamental thermal control surface degradation and contamination problems are compounded by life and survivability considerations in future high threat environments. Long-term storage of cryogenic reactants and cooling of large optic LWIR sensors require fundamental breakthroughs in cryogenic heat transfer and refrigeration. Directed energy and compact electronic packaging give rise to high heat flux-large area cooling requirements in excess of 100 kw/m² and 1m² areas. Burst and pulse power mission concepts will require fundamental solutions to the transient heat transfer problems implicit with these missions. Power system and payload radiator size, weight, and dynamic stability coupled with needs for evasive maneuvering and survivability require novel, basic research-born solutions. Thermal management of superconductors under fast transient loads is important for stable high power operation.

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RESEARCH OBJECTIVES

AEROSPACE POWER AND ENERGY

ENERGY SOURCES
DIRECT ENERGY CONVERSION
THERMAL MANAGEMENT

DYNAMIC ENERGY CONVERSION

ENERGY STORAGE AND CONDITIONING

TECHNICAL AREA COORDINATOR

ANTIPROTON PHYSICS

WEAPONRY

TECHNICAL AREA

WEAPONRY

INTRODUCTION

Modern weapons are becoming increasingly complex and sophisticated. This sophistication has significantly increased the cost of ownership and placed a large burden on the logistic system. New ideas and initiatives are required that will lead to weapon systems which will greatly increase force capabilities, are adaptable to varying battle scenarios, and can effectively perform at an affordable price in adverse weather conditions.

In addition to research on new weapon concepts, it is equally important to understand, and find ways to mitigate, the effects of nuclear weapons. These effects include the different types of radiation and the induced effects such as ground motion and electromagnetic pulses.

The effect of weapons on Air Force installations is also an important area of concern. New ideas and research which can affect the survivability of strategic structures, the rapid repair of tactical and logistic aircraft launch and recovery surfaces in a conventional warfare environment, the methods and equipment for damage avoidance and the unique requirements for maintenance and repair of Air Force real property facilities need continuing emphasis.

See also Project Forecast II initiative PT-26 Brilliant Guidance (section 9.1.11) seeking advances in sensors, multispectral seekers, signal processing, and artificial intelligence for imaging, acquisition, and tracking.

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SCOPE

Nuclear Weapon Effects, Subarea 6.1, consists of research objectives in low and high altitude nuclear phenomena; ground shock; transient and thermal radiation effects; X-ray effects; environmental, system generated and electron caused electromagnetic pulses; and nuclear weapons safety, security and reliability. These research objectives encompass the need to theoretically understand, predict, simulate, and verify the effects of nuclear weapons.

6.1.1 Low and High Altitude Nuclear Phenomena

Aerospace vehicles and ground based systems operating in a hostile nuclear environment and using optical, infrared, radar and communications systems are susceptible to the time dependent temperature, pressure, density, ionization, velocity, debris, dust and shocks associated with the fireballs of single and multiple nuclear bursts. At high altitudes, above approximately 80 kilometers, nuclear detonations produce radiation environments that strongly affect radio wave propagation and radar. The prompt radiation and the electrons that these detonations artificially injected into the earth's magnetic field pose a threat to satellites, particularly if the altitude of the nuclear detonation is above 100 kilometers.

Present theoretical calculations of low altitude nuclear phenomena are inadequate since they are based on physical phenomena that are not fully understood. To understand these phenomena, research is needed on the equation of state of atmospheric plasmas, on final state product distribution of atoms and molecules, on the effect of real earth surfaces, on the development of precursors to the airblast on the surface, and on excited state energy level structures of atmospheric triatomic species. To model nuclear effects on the propagation of communications and radar signals, research is required to specify the creation and dynamic evolution of atmospheric plasmas and the related chemistry. Research on nonlinear airblast interactions and the associated enhancements of area overpressure from coordinated height of burst detonations is necessary to quantify airblast enhancements from multiple bursts. To describe high altitude nuclear phenomena a wide variety of research in theoretical physics and the mathematics of partial differential equations is required to understand the motion and distribution of nuclear debris plasmas, debris induced plasma instabilities, the collisional and magnetic confinement of debris and subsequent ejection into the geomagnetic tail, nonlinear wave propagation, and shock interaction. Mathematical research on numerical methods is needed since existing algorithms do not permit an economical description of high altitude effects with sufficient spatial resolution.

6.1.2 Ground Shock and Cratering

The state-of-the-art of defining geological environments and determining their responses during dynamic loading from nuclear bursts is a major limitation in attempts to characterize ground shock and motion and crater dimensions for the purpose of siting nuclear weapons systems. To evaluate the effects of nuclear environments on surface or underground structures, models are needed that are capable of predicting the temporal and spatial variations in ground motions and stresses for varying geology, numbers of weapons, times of detonation, nuclear yields, and heights of bursts.

Research in the physical, geophysical and computational sciences is necessary for a wide variety of geological conditions to elucidate, predict and scale multi-dimensional ground shock effects for both single and multiple nuclear bursts. Of particular importance are multi-phase continuum models, finite difference models and non-phenomenological constitutive relations. Laboratory and field measurements with torsional shear devices are necessary to understand and provide a data base on the high strain levels of dynamic shear as well as simulation techniques to reproduce desired ground shock environments.

6.1.3 Transient and Thermal Radiation Effects

Transient radiation from nuclear weapons in the form of neutrons, gamma rays, x-rays and radio frequency electromagnetic waves and thermal radiation generated as a pulse during nuclear detonation cause deleterious effects in Air Force systems. Transient radiation may cause temporary or permanent degradation in many types of electronic and optical components including logic circuits, linear circuits, semiconductor memories, signal processors and optical data links. Thermal radiation affects aircraft and missile structures and optical and infrared sensors.

Research on transient radiation must include the basic mechanisms by which radiation can interact with materials and systems, such as ionization phenomena, charge transfer effects, neutron displacement damage, and charge trapping at material interfaces. The scarcity of data available on temperature dependent physical and mechanical properties of materials, particularly composites, is a major limitation in current calculations of thermal radiation effects. Data are needed on wavelength and temperature dependent absorptivities, discoloration temperatures, temperature dependent specific heats, thermal conductivities, coefficients of thermal expansion and the effects of temperature on material strengths. To verify the computational models based on these data it is necessary to use thermal test facilities to study the response of aircraft and missile structures and components. Evaluation of the response of sensors to thermal radiation pulses requires a detailed knowledge of the concentrations of radiating species as a function of time and space. Thus the necessary research includes formulation of chemical reaction rate equations and determination of reaction rates and radiation rates for important atmospheric and debris species.

6.1.4 X-Ray Effects

X-rays represent a large fraction of the total prompt radiation output of nuclear weapons. Investigations of x-ray response are necessary to assess vulnerability and hardness of Air Force systems in x-ray environments. Theoretical analysis, materials research, x-ray environmental simulation and x-ray effects simulation provide the means for realizing detailed knowledge and provide a basic understanding of energy deposition, stress generation and propagation, impulse generation, structural response, damage and material degradation.

The analysis and prediction of x-ray effects requires research on materials used for anisotropic heatshield, on hardness levels of materials such as graphite/resin composite that have potential uses as reentry vehicle structures, and on many other materials that are needed, for example, in rocket reactor cases and rocket motor linings. Further research is required on the equation-of-state in the liquid, liquid-vapor and vapor regions for heatshield constituent materials. Research in numerical analysis is necessary to alleviate current uncertainties associated with numerical stability and nonlinear response in x-ray effects structural codes.

There is continuing need to realize the technology to simulate x-rays in a laboratory for space systems survivability assessments. High density plasma x-ray sources appear most promising for providing the required X-ray spectrum and fluence. A wide range of theoretical and experimental research is needed to understand the physical processes occurring in the devices including plasma production and radiation processes in plasmas; to diagnose the spectral, temporal, and spatial characteristics of emitted radiation; to enhance radiation output; to improve energy storage and pulsed power for these systems; and to understand the scaling of x-ray outputs.

The deficiencies of present x-ray environment simulators as to total output fluence, flux and spectral content limit their use and we must rely, in part, on effects simulators at the present time. The pulsed electron beam is such a simulator; however, for this device energy deposition is influenced by space charge effects. Both theoretical plasma physics and experimental diagnostic techniques are necessary to fully understand the role of space charge effects in effects simulators.

6.1.5 Environmental, Systems Generated and Electron Caused Electromagnetic Pulses

The interaction of the radiation from a nuclear burst with the environment produces a large electromagnetic pulse (EMP) that can propagate great distances from the nuclear burst. In addition, nuclear photon interactions with systems and nuclear charged particle deposition in system dielectrics produce system generated electromagnetic pulses (SGEMP) and electron caused electromagnetic pulses (ECEMP), respectively. These electromagnetic pulses can induce transients that cause malfunctions or destruction of critical electrical and electronic systems and components. These critical systems and components include integrated solid state circuits, data processing circuits and components, connector pins, cables and solar cells.

The approach to minimizing the deleterious effects of EMP, SGEMP and ECEMP consists of predicting or simulating both the strength of the electromagnetic pulse at a given vulnerable system, predicting the interaction of the EMP with the system, evaluating the thresholds for malfunctions or destruction for specific systems, verification of hardness for each particular initial system, and surveillance and maintenance of hardness throughout the operational lifetime of the system.

Extensive research is required in both equilibrium and nonequilibrium plasma physics to improve and validate models for EMP in a variety of physical situations including free field environments, source region coupling and low air density. The effect of atmospheric composition and electronic kinetics in the radiation-induced current flow and conductivity needs to be understood for large transient electric fields. Research in theoretical physics and mathematical physics is needed to describe electric field stability and growth in complex nonlinear media, to devise algorithms for statistically refining experimental data, and to formulate models of scattering phenomena. Large scale computer simulations of EMP effects must incorporate information concerning all of these physical phenomena. Research is necessary to determine the electromagnetic stress on external and internal portions of systems. The physical phenomena associated with variable EMP damage thresholds must be fully identified, modeled and characterized experimentally. For SGEMP and ECEMP, electron and photon interactions with materials and systems have to be investigated with emphasis on charging/discharging of dielectrics and inhomogeneous energy, radiation and charge transport; furthermore, the subsequent system response must be modeled. Research issues associated with EMP simulation include EMP generation and propagation in plasmas, nonlinear coupling in the EMP source region, pulsed power research for improved trigger switching speed and higher energy sources, EMP interactions and theoretical formulations to predict the scaling of EMP phenomena.

6.1.6 Nuclear Weapons Safety, Security and Reliability

During the past 10 years there has been a major increase in the sophistication and capabilities of the unconventional and terrorist threat. These politically motivated groups with active aid from unfriendly countries have significantly increased their ability to plan, execute, and successfully accomplish attacks against a wide range of targets. These evolving capabilities have led to a decrease in our ability to protect nuclear weapons with the high degree of reliability required by regulation. Security systems used in the warning and protection system for nuclear weapons have high false alarm rates and require man-intensive support. Increased sophistication of the threat coupled with ever-increasing demands on the Air Force Security Police Forces require significant improvement in detection assessment and warning systems to increase their reliability and decrease the requirement for manpower-intensive support.

Another aspect of security assessed for nuclear weapon systems is Unauthorized Launch (UL) threats. The Unauthorized Launch Analysis identifies all methods that agents may take to effect a credible UL threat. A major portion of the information is derived from the responsible contractor's Launch Action Studies. The agency responsible for the UL develops a launch activation path which

includes hardware, software, firmware and codes that control critical functions and could contribute to an UL. Items that contribute to UL scenarios become critical components. Critical components are components that actively control the critical functions identified by the four DOD nuclear weapon system safety standards. The cost effective way of conducting an UL study is through the use of a system approach that uses the launch activation path techniques.

Research is required on nuclear weapons logistics. Nuclear weapons storage and movement signatures have remained essentially the same over the last 25 years. This problem is related to the first paragraph above. Storage and transportation systems were designed and built generally over 25 years ago. Modern weaponry has outstripped the defensive capability of these systems and this, coupled with the greatly increased sophistication of terrorist groups, increases the probability of success of these groups if they choose to mount an effort to capture a weapon or create an incident.

Nuclear surety (safety and security) design guidance is continuously being developed and revised to ensure compliance of nuclear weapon systems with the four DOD nuclear weapon system safety standards. An aggressive program must be established and maintained to incorporate applicable nuclear surety criteria in the various subsystems of a nuclear weapon system, e.g., ground handling equipment, command and control, nuclear weapon security, unauthorized launch and others. Nuclear surety certification of a nuclear weapon system signifies compliance with the four standards.

Research and study is required to develop the interface between physical security (access control) and the internal weapon security (use control). This effort should include enhancement of command and control techniques and devices which overlay both access and use control.

6.1.7 Nuclear Radiation Transport (Air-Over-Ground)

The ability to predict accurately hostile nuclear radiation environments due to neutron and gamma-ray weapon output provides useful information for setting design criteria and operational plans for future and present Air Force weapon systems. These neutral particle environments are accurately predicted for endoatmospheric scenarios by experienced users of complex and expensive transport codes. Engineering codes, based on parametric fits to transport data bases, alleviate the necessity for user expertise in transport codes and allows the prediction of multiple environment scenarios in a quick and cost effective manner. Current engineering codes give user the abilities to predict total dose for both homogeneous air and air-over-ground scenarios.

While the homogeneous air scenarios are adequately solved for burst and receiver locations less than altitude of 20 km, further research is necessary to develop a more versatile air-over-ground engineering code. The current air-over-ground engineering code is based on a particular data base and therefore cannot allow for different ground compositions which may have an important effect on results. Research in this area must be continued in order to develop a code that can account for the major variables in an air-over-ground environment and yield accurate and timely results.

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SCOPE

The 6.2 subarea identifies research objectives (ROs) associated with conventional weapons. The term conventional weapons comprises non-nuclear warfare devices employed to destroy or incapacitate enemy targets. The individual ROs address the various subsystem technologies needed to advance the state-of-the-art. Specifically addressed are the technology objectives associated with guided weapons, direct fire weapons, munitions and weapons analysis. The guided weapons research objectives include work in guidance and control, sensors and seekers, and signal processing. The research in direct fire weapons considers propellants and interior ballistics, aeroballistics, and electromagnetic launchers. The munitions research addresses explosives, warhead/target mechanics, and aerodynamics. The research in weapons analysis is concerned primarily with simulation.

6.2.1 Guidance and Control

The dynamic behavior of a guided conventional weapon system depends upon the control strategy employed, the estimation technique used to monitor system behavior, the mathematical model employed in the controller, and the evaluation of the weapons system effectiveness. A similar requirement exists in controlling aerospace vehicles of the dynamics of a jet engine and is described in research objectives 4.3 and 5.2. However, control system strategy employed for guided conventional weapons differs from that of aerospace vehicles in that it is usually of shorter duration, is concerned with higher g force environments and has lower lifetime requirements. Present techniques employed for tactical missile guidance and control fail to provide suitable missile responses throughout the full range of flight dynamics. The need to compile and store an enormous amount of dynamic data on the various states of the missile/target engagement are not currently satisfied. Research is needed to develop robust guidance algorithms that explicitly account for system state/parameter uncertainty and/or denial for applications in highly nonlinear, time varying tactical missile systems. Further, these guidance algorithms must be implementable on board the missile via microprocessor based controllers and solvable in real time. Research should address new techniques that use the important nonlinear aspects of the control problem and the multivariate digital control methods. Additionally, research is needed in developing advanced guidance laws that are compatible with strapdown seeker systems that provide angle, range, and range-rate information while suffering degradation by missile body motions. These seekers require boresight error slope compensation. Efforts should be initiated to investigate techniques for determining boresight error slope in real-time without prior knowledge of random transmission characteristics. The application

and extensions of guidance and estimation techniques that explicitly include state estimation enhancement should also be considered. Research should address new techniques that account for important nonlinear aspects of the control problem and which make use of multivariate digital control methods. The application and extension of guidance and estimation techniques that explicitly include state estimation enhancement should also be considered. Research which investigates new nonlinear estimation methods is needed. Potential areas of exploration are stochastic modeling of target acceleration and identification of target acceleration through new filtering techniques. Research into the coupling of autopilots with optimal guidance laws for highly dynamic air-to-air missiles is needed. Finally, research in the interaction and simultaneous design of guidance and thrust control should be pursued.

PT-26 Brilliant Guidance is a technology program under Project Forecast II. Brilliant Guidance incorporates and integrates all relevant technologies required to develop a family of autonomous airborne weapons that acquire, track, and guide to a variety of air and surface targets without post-launch communications. Brilliant Guidance would increase delivery aircraft survivability and kills per pass by launching all weapons while the aircraft is in "friendly" territory. This technology will also reduce pilot workload and training requirements since post-launch communications are not required.

6.2.2 Sensors/Seekers

The effectiveness of air-to-surface and air-to-air guided weapons is limited by deficiencies in understanding the complex nature of target signatures (passive, active, and semi-active as well as natural), as well as the ability of the seeker to operate under severe military environments. Seekers are needed which are compatible with supersonic delivery; can withstand high-g load maneuvers; provide good accuracy; can be packaged in small volumes to allow overall reduction in missile size; are lightweight, low powered, and inexpensive, and are capable of operating in intense electronic warfare environments at extended firing ranges. There is a great need to quantify the effects of adverse weather on seekers and sensors. Requirements for all weather strike capability emphasize the need for further research in atmospheric effects on target acquisition and tracking capabilities.

Besides evolution of existing seekers/sensors, research into fundamentally new concepts such as detecting and tracking properties of multiple aperture optical systems should be pursued. Synergistic combinations of sensor information should be investigated. This includes a study of basic trade-offs between physical characteristics of targets and capability of apertures. Consideration should be given to investigating naturally occurring eye processes in order to understand the wide-field-of-view arrays and associated guidance phenomena.

6.2.3 Signal Processing

The effectiveness of air-to-surface and air-to-air weapons and weapon delivery systems has been limited by deficiencies in the areas of target detection, identification, classification and centroid location. This is primarily true in the presence of multiple targets, highly cluttered backgrounds, adverse weather, and ECM conditions. Improved mathematical

structures suitable for modeling, designing and analyzing pattern recognition algorithms will be critical to the optimization and maintenance of signal processing software in future autonomous guided weapons.

High data rates required by existing weaponization concepts require innovative research leading to the development of advanced digital machine architecture for signal processing implementations. Research which addresses the advantages and limitations of digital and optical signal processing techniques is required. The feasibility for implementing digital, optical, and/or hybrid (i.e., digital and optical) processing techniques to meet the signal processing requirements of future weapons should be considered. Improved pattern recognition pre-filtering concepts for autonomous midcourse and terminal guidance systems are also needed. Application of artificial intelligence to target discrimination recognition and classification should be investigated. Finally research leading to the development of optical processing components which are suitable for use in tactical guided weapons is highly desirable.

6.2.4 Propellants and Interior Ballistics

Virtually all analyses regarding the lethality of aircraft cannons result in the conclusion that the time of flight to target for the projectile must be shortened. The most direct means to this end is to provide a major increase in the muzzle velocity of the cannon. The primary factor which inhibits the development of existing aircraft cannon performance is barrel erosion due to high performance propellants. Research is required which investigates the combustion mechanisms of nitramine propellants, the burning rate depressant effect of deterrent ingredients, and the basic mechanisms of flash suppression and smoke formulation as a result of the combustion process in gun propellants. Research results which will provide the technology base necessary for the development of high energy, progressive burning, low flame temperature gun propellants are needed. New energetic compounds which offer significant increases in performance need to be identified and synthesized. The effects of particle size and solid oxidizer/binder bonding influences on propellant morphology and combustion need to be considered. In addition, research which defines the forces between the projectile rotating band and the gun barrel is needed. Emphasis here should be given to engraving and postengraving regions as well as defining theoretical expressions to model these interactions in the combustion environment.

6.2.5 Hypervelocity Launchers

The great desire for reduced time of flight for aircraft launched projectiles, together with limiting factors for projectile acceleration from chemical energy sources such as conventional propellants, suggest that basic research is needed in fundamentally new projectile acceleration devices. Several techniques or approaches for achieving velocities exceeding 10,000 ft/sec have been proven feasible for a single shot. These include electromagnetic launchers, electromagnetic gun, and ram cannon. Research at all component and subsystem levels which will establish the technology base for weaponizing these devices for rapid fire applications is required. Particular attention should be given to minimization for size and weight.

6.2.6 Explosives

Chemical energy explosives have been used in weapons for centuries. However, research into phenomena related to energetic materials has been systematically performed only since World War II and much of this research has been empirical. As a result, extensive research needs still exist. We do not have a complete knowledge of the species in the reaction zone or the reaction products of a detonation. For example, the equation-of-state of the detonation products is central to determining energy flow in explosives; however, equations-of-state of complex solid explosives still cannot be derived. In addition, the time history of the energy release in the reaction zone is unknown for nonideal explosives.

With increasing weapon delivery speeds and the increasing hardness of targets against which weapons must be effective, the environment in which the explosives must function is also becoming more severe. Explosives are needed that are capable of surviving high heating and shock pulse environments while functioning properly in a safe manner at a reasonable cost. Fundamental chemical and physical properties of explosives should continue to be analyzed with emphasis on understanding properties related to maximum energy content. The potential of using new formulations containing energetic plasticizers or binders should be considered. Research into the synthesis and characterization of intermolecular ingredients of eutectic explosives is needed. Research into how the molecular structure of explosives relates to chemical bond stability, susceptibility to long/short term thermal decomposition, detonation initiation, kinetics of detonation and explosive energy distribution is also needed. Finally research into the effects of particle size, viscosity, density or susceptibility to heat and humidity should be examined to determine their relationships to chemical structure and physical state.

6.2.7 Warhead/Target Mechanics

The ultimate measure of a weapon's effectiveness is its ability to destroy either partially or totally the enemy target. Research into a very wide variety of chemical and kinetic energy warheads and their interactions with an equally wide variety of targets is required. Warhead kill mechanism interactions with target structures are difficult to describe analytically because of the diversity and complexity of the interactions, and the extreme nonlinearities that accompany these interactions. In order to predict when failures will occur, valid failure criteria and the loading path involved must be known. Also, the effects of blast loads are different from loadings due to projectile or fragment penetrations, and these are both totally different from incendiary reactions. Moreover, all these kill mechanisms may occur simultaneously, sequentially, or individually. As a result, target preconditioning may occur or synergistic effects may be produced where total target damage from simultaneous kill mechanisms exceed the sum of the individual damage effects. Research is needed in basic target structure reactions to kill mechanisms, the various loadings that are produced by the kill mechanisms throughout the target structures, and, in the case of penetrating weapons, the effect of the target on the weapon.

Our predictive capabilities for weapons is greatly hampered by the lack of adequate material properties. Some typical examples are in armor penetration, target shock interaction, liner behavior in shaped charges, material behavior in self-forging fragments, explosive sensitivity, and performance.

Research needs to address material properties of shaped charge jets and self-forging fragments under dynamic conditions (high strain rates). The phenomena and target penetrator interaction must be researched in detail, e.g., gaining a more fundamental understanding of the phenomenon occurring during dynamic fracture such as nucleation of cracks, which subsequently contributes to failure and material separation.

6.2.8 Aerodynamics

A wide variety of specific requirements such as kills of highly maneuverable targets, the desirability of aircraft standoff, offboresight launch conditions and safe aircraft/weapon separation dictate a continuous research program in conventional weapons aerodynamics. For such a program to succeed, a fundamental understanding of fluid mechanics and flight mechanics for steady and unsteady flow must be achieved. The technology to predict and evaluate aerodynamic and stability characteristics of symmetric and asymmetric missile airframes over large variations in Mach number, angle of attack, angle of sideslip, and high angular rotation rates is also needed. Attention should be given to asymmetric airframes for the transonic through hypersonic Mach number regimes. Regions of separated flow including shallow cavities should be studied to determine their effect on drag, heating, control authority, and trajectory characteristics.

The most complicated and perhaps most critical area of conventional weapons aerodynamics research is for the aircraft/store combination. No purely analytical solution exists which is capable of replacing costly wind tunnel testing for store separation analyses. Current linear techniques are incapable of handling compressibility, mutual interference, and shock interference problems. As a result, nonlinear computational fluid dynamic techniques applicable to multiple store configurations are required. Fundamental research into the complete numerical solution of the Navier-Stokes equations for aircraft/store carriage and release is required.

6.2.9 Weapons Analysis/Simulation

To improve criteria for air-to-air and air-to-ground weapons, research must be conducted in computer based modeling and simulation, optimization techniques, decision/game theory and related aspects of control theory. Effective analysis of armament systems requires information from a multitude of technical disciplines associated with the systems, such as safe-separation and release, guidance and control, inflight stability, fuzing and terminal homing, terminal accuracy, target encounter geometry, warhead detonation and fragmentation characterization, warhead kill mechanism interactions with target structures, and target sensitivities to warhead kill mechanisms. Research which addresses representation of realistic environments through digital simulation while simultaneously reducing computer requirements is of great interest.

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SCOPE

The 6.3 subarea identifies research objectives associated with high energy lasers, particle beam systems, high power microwave and millimeter wave weapons, other directed energy weapon concepts and the applicable power for their operation. Areas identified for research in high energy lasers include lasing mechanisms, laser device components, beam propagation, pointing and tracking, and radiation-target interaction. Particle beam system research areas include ion source accelerators, particle beam propagation, pointing and tracking, and particle-target interaction. High power microwave and millimeter wave research areas include generation mechanisms, frequency stabilization, phase locking, signal amplification, pulse characteristics selection, radiative structures, high power propagation, and radiation target interaction. The Air Force must continually address the potential for novel and advanced weapon concepts which may offer advantages over present systems in a variety of scenarios. In this regard, we must assess from a fundamental technological level those concepts which may offer advantages in the future. Among these novel and advanced weapons concepts are microwave weapons, plasma projectile weapons, and hypervelocity projectile weapons. These weapon concepts would exploit opportunities that arise from the Nation's overall R&D effort as well as those from specific weapon development programs.

High Energy Lasers

Research needs in the high energy laser program are concerned with both the development of refinements to improve the efficiency and capabilities of currently existing high energy laser concepts and the investigation of advanced concepts with the potential for significant improvements in the state-of-the-art. To date, the most mature technology is for high energy laser systems at infrared wavelengths. However, high energy lasers operating at shorter wavelengths offer the promise of high brightness and increased range of comparable optic size. Current research has identified only a limited number of high energy laser candidates in the visible or near-ultraviolet. The development of this advanced technology and the investigation of other new concepts must continue.

6.3.1 Lasing Mechanisms

Fundamental studies are required not only to search for new laser candidates but also to fully understand the mechanisms in those already identified. Investigation techniques should include a mixture of experiment and theory. Theoretical and experimental determination of energy exchange processes in excitation and de-excitation should include the determination of reaction rates, cross sections, rate constraints and mechanisms. Calculations and measurements should be made of the distribution of vibrational, rotational, and electronic energy level populations for reaction products. Atomic and molecular properties of reactant and product species must be fully characterized to include oscillator strengths, Franck-Condon factors, location and order to energy levels, dissociation energies, ionization potentials, and electron affinities. Improved potential energy surfaces for the species

and reactions of interest should be determined. Both resonant and non-resonant mode-media interactions must be considered and understood.

Chemical laser technology also needs support in basic phenomenology. Studies are needed to ascertain the nature and behavior of intermediate chemical species produced in reactions involved in current and potential future chemical lasers. Such species are intimately involved in the lasing process and contribute to overall reaction rates efficiency, beam quality, and deactivation processes. Better nonintrusive/diagnostic techniques are required. New precursor chemicals are needed which combine efficient lasing species with good storability and handling safety. Research is needed on the low pressure, supersonic mixing of fluorine and deuterium, as well as other chemical reactants. Better theoretical and experimental modeling of the mixing and flow characteristics occurring downstream from the exit plane of the chemical laser nozzle bank must be pursued. Techniques must be developed to ensure efficient pressure recovery for low Reynolds number supersonic/hypersonic flows. A more complete understanding of the energy transfer between excited oxygen and iodine must be obtained. New iodine atom injection techniques are needed for the iodine laser operating in the supersonic flow regime. Chemical transfer rates for producing excited nitrogen must be investigated and experimentally measured. Finally, fundamental studies of energy transfer mechanisms and kinetics between other chemically generated excited species and suitable lasing species are needed, with emphasis on visible or non-ultraviolet laser concepts with the potential for efficient, high power operation.

Notable among current concepts for shorter wavelength laser devices are free electron laser and excimer laser devices. The principles of free electron lasing (FEL) are now being developed both theoretically and experimentally. These proof-of-principle experiments will open great avenues of promise and problems for the future development of this technology. Reducing the FEL concept to an efficient and practical device will require extensive research into the principles underlying the many parameters of a free electron laser. For excimer lasers, continued research is essential to develop the potential of this concept for high power pulsed applications. Investigations of excitation mechanisms and kinetics are needed to improve efficiency and to understand the tradeoffs between single pulse and repetitively-pulsed operation. Current concepts for producing a high quality beam from high power excimer lasers involve the use of high power Raman cells; research is critically needed to establish the feasibility and efficiency of this technique and to evaluate other concepts to produce good beam quality. The technique most promising for improving beam quality and increasing brightness is the concept of using phase conjugated backscatter from a Stimulated Brillouin Scatter (SBS) as the beam cleanup scheme.

6.3.2 Laser Resonator & Optical Components

Critical advances are needed in resonator technology and in optical materials and fabrication technologies. Improved design and performance prediction capabilities are needed for cylindrical resonators, decentered rings, coupled/shared resonators and other advanced resonator configurations. With respect to resonator modeling, there is an urgent requirement for accurate simplified models of current and projected high energy laser systems. Areas of interest include development of a rapid convergency algorithm to solve the nonlinear integral equation for loaded resonator problems and application of asymptotic and analytic techniques to analyze resonator performance. There is a particular interest for cases where the resonator is influenced by perturbations such as misalignments, misfigure, and gain medium effects.

All aspects of component fabrication need considerable improvement if optical components capable of meeting performance goals in a system environment are to be produced efficiently. Particular emphasis must be given to studies of heat exchangers, optical surfaces and coatings, which are crucial factors in limiting the range of optical flux and, thus, a primary constraint on system size. Since material properties in this film form are considerably different from bulk properties, a more systematic investigation of coating materials, including optical and mechanical properties, damage mechanisms, damage thresholds, and environmental stability, is required. Effects of various surface figuring and finishing techniques, such as single point diamond turning, mechanical polishing, and noncontact methods using laser/ion beams, need to be further explored to determine impacts on coating properties and optical distortions. Efficient means to uniformly coat larger more complex optical surfaces for applications involving multiple wavelengths must also be developed.

New substrate materials and more economical fabrication processes, which provide stable components for extended use, need to be investigated. Novel cooling approaches that produce less jitter and greater simplicity of design such as passive phase cleanup material heat exchanger should be examined. Processes and materials for producing improved beam sampling and aperture sharing components must be developed. Requirements for higher spatial frequency and faster response times for wavefront distortion correction and control necessitate improvements in deformable mirror design and construction.

One wavelength region of current emphasis for optical component development programs is the visible to near IR region (.3 to 1.5 microns). The major concern in this short wavelength region is the resultant optical performance. At shorter wavelengths new laser device technologies are showing promise, among these are the FEL and the excimer laser which are currently undergoing development at low power. The implementation of higher accuracy resonator optics and other components for short wavelength applications presents tremendous technological challenges. Extensive research in design, materials and fabrication will be required before the highly promising attributes of visible UV devices may be utilized effectively. As the transition to realistic applications approaches, more attention must be given to materials and fabrication techniques that will provide stable elements suitable for extended use in a system environment.

6.3.3 Propagation

Research is required to improve the understanding of the numerous constraints on high-energy laser beam propagation. Particular attention must be paid to problems associated with laser beam propagation in naturally occurring atmospheric environments. Specific factors are phase aberration effects, absorption and scattering by molecular and aerosol atmospheric constituents, kinetic cooling effects and boundary layer effects. Coherent adaptive techniques must be developed that allow for compensation of phase aberrations due to system generated and atmospheric induced distortion. Basic research is needed in order to identify the scope, nature, and characteristics of these effects in order to better understand the magnitude of the compensation problem. Theoretical modeling of aircraft-induced turbulent boundary and shear layer effects is needed. Measurements involving high

energy beams become more difficult as power level increases. New techniques are needed to measure beam parameters such as power, centroid, jitter, size and shape as the beam propagates through the atmosphere. New detectors with fast thermal response and uniform bandwidth need to be developed, and detector array spatial and temporary sampling optimizations need to be investigated.

6.3.4 Pointing and Tracking

Beam control involves the actual pointing of the laser beam and the tracking of the designated target. Accurate tracking of small targets at significant ranges requires advanced concepts in active and passive sensors. In some engagements, target imaging is required to allow aimpoint designation. This implies a requirement for very high angular resolution at fast frame rates. Reliable stable methods are needed for detecting where the high energy beam hits the target with respect to the desired aimpoint and then providing closed-loop corrections. New digital control algorithms are required to successfully integrate all beam control functions. Technology advances are required in structural materials, bearings, structural control and vibration isolation methodologies, sensors, actuators, stabilization techniques, adaptive optics, advanced tracking and control algorithms. Stiff, nonresonant structural materials and rotational bearings with low friction but low compliance in radial and axial directions are needed. For certain applications, it appears that active structural vibration control and enhanced isolation of residual structural vibration from the control optics will be required. Improved vibration sensors and controllers as well as enhanced isolation mechanisms are needed. Low-noise, wide-frequency--bandwidth motion sensors for inertial stabilization of fine precursor pointing mechanisms are required. New concepts for high-bandwidth, heavy duty actuators, both rotational and translation, for driving or stabilizing large mirrors, telescopes, or platforms need to be pursued. In laser beam stabilization problems it is necessary to cause reflecting mirrors to move through angles which are precisely those being experienced by the mirror's mounting base. For longer range engagements, the problem is even more severe, and additional advances will be required in beam stabilization techniques. New materials, better theories and more experimental work are required to advance the understanding of nonlinear optics systems to where they can be incorporated into system design.

6.3.5 Beam-Material Interaction

Laser interaction with a target depends on laser beam parameters (wavelength, flux, spatial profile, temporal variations, and incidence angle), the target material and its surface morphology, and the environment surrounding the target. In order to successfully evaluate the utility of near-infrared and visible lasers (cw, pulsed, and repetitively pulsed) for military missions, it is necessary to undertake experimental and theoretical research work. Research is needed for the response and damage produced by laser irradiation of relevant aerospace materials and countermeasure concepts in physically correct environments. For pulsed and repetitively pulsed laser irradiation, it is necessary to develop experimental data and theoretical models for such phenomena as plasma ignition and maintenance requirements, plasma radiative and propagation properties, and target damage phenomena (enhanced thermal coupling, rupture/buckling, spall, thermal and/or mechanically-induced stress fracture, surface roughening, delamination, and in-depth deposition effects).

Particle Beams

Intense particle beams of atomic or subatomic particles are of interest as potential advanced weapons. Such beams would travel near the speed of light and be highly lethal because of their volumetric energy deposition and generation of lethal secondary particles. Research requirements differ, depending on whether applications are endoatmospheric or exoatmospheric particle beam systems.

Endoatmospheric applications are paced by lack of a demonstrated propagating beam. Presently, the technologically limiting factor is the development of an accelerator capable of producing an appropriately intense beam of sufficiently high energy to demonstrate propagation. The specific choice of particle species (ions or electrons) depends to a large extent on acceleration techniques and propagation characteristics. Research on the physics of propagation in the atmosphere for pressures equal to or less than one atmosphere is of strong interest.

Exoatmospheric applications are paced by technology. Few questions concerning propagation remain since neutral beams will propagate in a vacuum. There are, however, unresolved issues concerning more esoteric schemes such as plasmoids and neutral plasma clouds. Critical technological areas revolve around intense ion sources with low emittances, controlling space charge effects at low energy ends of accelerators, beam control optics and pointing and tracking to include target return signatures. A general problem area of directed energy weapons is damage assessment/kill determination and fundamental research programs should be directed toward new or improved assessment techniques.

6.3.6 Ion Sources

Negative ion sources for exoatmospheric applications require continued research in new approaches. The criteria for satisfactory refinement of present sources and successful new sources are severe, especially in the areas of lowered emittance and noise, scalability, high brightness, and desirable extraction and injection properties. A fundamental theoretical understanding of negative ion formation and noise generation in sources is needed. Improved diagnostic techniques for all charged-particle sources are also required.

6.3.7 Accelerators

Accelerators are required for the demonstration of key physics issues in propagation, target interaction and sensor observables, and for the eventual applications. The parameter regimes are distinct for the endo and exo-atmospheric applications.

For each application (neutral or charged), there exist conventional approaches involving the extension of current technology with relatively low risk, and novel approaches which promise high payoff in, for example, size and weight. Opportunities exist for basic theoretical and experimental research with all accelerator concepts. Exoatmosphere issues include research topics such as emittance growth, high-gradient concepts, beam-dynamics-transport modeling, new concepts analyses and improved diagnostics methods.

6.3.8 Propagation

Successful particle beam propagation in air is mandatory for useful endo-atmospheric applications. Propagation requires creating a reduced density channel with early pulses of a multiple pulse train. Subsequent pulses must then follow the channel with reduced attenuation. Topics requiring additional research include, basic air thermochemistry, beam--instability theory and modeling, and propagation along density gradients.

Information about exoatmospheric propagation of neutral beams appears well in hand, but penetration of neutral beams into the atmosphere needs additional research. Research opportunities do exist in examining the propagation of charge-neutral plasma beams (plasmoids) and charged particle beams over substantial distances both outside of the atmosphere and in the upper atmosphere. For all the above research, in addition to theoretical investigations, the need exists to perform experiments with suitable diagnostics to validate models.

6.3.9 Pointing and Tracking

The potential use of high energy beams for Air Force applications requires the ability to accurately deliver the beam energy to the intended target. One portion of this beam control task is beam sensing--detecting the beam location--both near the accelerator and near the target. This remains a critical research area.

Many potential applications of high energy beams involve the engagement of moving targets at significant ranges. To improve the ability to perform these engagements, continued research is needed to improve target tracking and beam pointing accuracies for large aperture pointing systems in the presence of external vibrations and unsteady torques. Accurate tracking of small targets at significant ranges requires advanced concepts in active and passive sensors. Reliable, stable methods are needed for detecting where the high energy beam hits the target with respect to the desired aim point and providing closed-loop corrections. This process is difficult to implement because of complicated beam-target interactions.

6.3.10 Beam-Material Interaction

The ultimate utility of a particle beam weapon depends upon how it interacts with targets. Beam-material interaction studies must receive a reasonable degree of emphasis in any systematic balanced research program in weapons applications of particle beam technology. Considerable effort has already been expended and the basic research area is reasonably mature; however, potentially high impact areas remain to be investigated. Topics requiring further study include areas such as nuclear radiation emitted from thick targets due to high energy ion bombardment, thermo-mechanical damage mechanisms, multipulse collective interactions, energy deposition mechanisms and materials response.

Weapons Power Systems

6.3.11 Power Generation

The generation of prime power for space-based weapons systems is a most critical research area pacing advanced directed-energy systems. Future Air Force space missions will require substantially higher power than is now available. This involves many-fold increases above present space system capabilities in both power levels and total energy. Multimegawatt, gigajoule power sources, light in weight, efficient, and adaptable systems for prolonged operation in the space environment will be needed. Research is needed to conceive and pursue promising concepts for the generation of these unprecedented space power requirements. Explosive, rotating, and battery driven sources are some examples of present concepts which may provide the needed power.

6.3.12 Power Conditioning

Appropriate power conditioning is an important requirement for some directed-energy weapon systems and their auxiliaries. The high power requirements and the particular characteristics of weapon systems will require new developments in such areas as pulsed power technology and energy storage. Concurrent advances in the state-of-the-art of a number of sciences will be necessary to accommodate the high demands of these developments. High-temperature, high-strength materials and high density energy storage materials (dielectric, magnetic, electrode) are specific examples. Many existing weaponry research objectives discuss the required development of advanced fast-discharge, high-energy density or compact high average power electrical systems. In addition, most advanced weapon concepts under study are based on high power electrically driven generators, accelerators or transducers. Thus, to this wide range of applications, pulsed power technology is a necessary and supporting field of endeavor. Furthermore, related technologies such as inertial and magnetic confinement fusion, radiation simulation and lasers also have critical pulsed power requirements. For Air Force applications, high energy density, i.e. low-weight, small-volume power systems are required. Other concepts, particularly those that use large arrays of modules, require system hardware and software for implementation.

Accurately timed, low-jitter switching is a common requirement of most advanced systems. New closing switch concepts with improved repetition rate, voltage and current capabilities are among the major determinants in developing accelerator designs. Concepts for both low and high repetition rate opening switches are essential for the development of high energy inductive storage and the eventual design of compact systems.

Energy storage candidates include inductive and capacitive energy stores, flywheels and homopolar generators, flux multipliers and MHD devices. Research into energy storage and switching techniques vastly different from those in common practice today will be needed to fulfill the requirements. Also needed is research supporting the power conditioning technologies associated with such prime energy sources as explosive, rotating, battery, and line power driven sources.

Other Directed Energy Weapons

6.3.13 Microwave and Millimeter Wave Weapons

High-power microwave and millimeter wave radiation has high potential as advanced weapons. These sources are capable of the destruction of systems by Joule heating and breakdown through induced voltages in critical systems components. At lower energy/power levels, "dumb" jamming may be possible at significant source-to-target distances. To realize the necessary high-power radiation sources, experimental and theoretical research must investigate collective plasma and electron beam phenomena that offer the potential of generating high-power radiation. These include plasma and collective phenomena such as collective electron-ion emissions, virtual cathode radiation, the collapse of electron or ion waves, the negative mass instability, the modulational instability and the Cerenkov instability.

6.3.14 Hypervelocity Projectile Weapons

Hypervelocity projectiles (velocities 1500 m/sec, projectile energy 1 megajoule/m²) are extremely effective against particular types of targets. In general, such projectiles are accelerated by shock hydrodynamic techniques, although the possibility of electromagnetically accelerating the projectile has been examined. Additional experimental and theoretical research is required in the fields of projectile production and acceleration, aerodynamics and stability, and target damage.

The understanding of Taylor instabilities gained from the laser fusion program should be applied to the problem of hypervelocity projectile production and additional studies performed as appropriate. Electromagnetic acceleration techniques should continue to be explored with particular emphasis given to limitations on projectile acceleration that result from magneto-mechanical strength considerations. Although addressed under separate ROs, note that major advances are required in high power technology in order to implement electromagnetic acceleration techniques.

Aerodynamic considerations will place limits on the flight regimes where hypervelocity projectiles can be used. Research should help define these limits and provide sufficient understanding of the basic mechanisms involved so that the potential for aerodynamic improvements can be established.

Although considerable work has been done in the area of hypervelocity impact, fundamental work must be continued on the understanding of shock hydrodynamics in both ideal and real materials. Extensions of our present understanding of pure materials to understanding structures in several dimensions is required. Major advances in multidimensional shock hydrodynamic codes are needed in order that target damage can be calculated in reasonable time using advanced computers.

The effectiveness of millimeter or micron-sized particles as hypervelocity projectiles has not been analyzed. This size lies between the conventional hypervelocity projectiles and the molecular sized particle of particle beam systems. Imaginative and definitive studies are needed to establish the system characteristics and usefulness of this range of projectile sizes.

6.3.15 Plasma Projectile Weapons

Plasma projectiles are ensembles of plasma which have been accelerated to large velocities. These plasmoids may have velocities in the range of 100 Km/sec to 100000 Km/sec. Plasma densities could range from 10^{16} to 10^{23} m⁻³. Acceleration of these plasmoids may be accomplished by any of a variety of devices. Research needs to be conducted in the areas of plasma acceleration, plasmoid propagation, plasmoid tracking, and plasmoid lethality.

In particular, definitive data regarding the physics of acceleration of dense plasmas needs to be gathered. Scaling laws governing the acceleration process must be elucidated. The plasma temperature after acceleration is a critical parameter, since the spreading of the plasmoid after launch is determined in large part by the internal energy of the plasma. The stability of the plasma during acceleration will limit the final velocity which may be obtained with a given length of accelerator.

Considerable work needs to be done regarding the propagation of plasmoids in vacuum and near vacuum environments. Plasmoids with and without embedded magnetic fields must be evaluated with regard to their propagation techniques. Interactions of the plasma with the surrounding medium must be understood. Major advances in multidimensional magnetohydrodynamic codes are needed to model these effects in a reasonable amount of computer time.

Finally, the interaction of plasmoids with material targets requires further elucidation. The wide range of material densities and characteristic scale lengths present in plasma/target interactions renders computational simulation extremely difficult. Sophisticated multidimensional shock hydrodynamic codes capable of adaptive mesh generation are needed to model these situations.

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SCOPE

The Civil Engineering Technology Subarea Research Objectives encompass requirements for research to insure survivability of mission essential structures and lifelines in nuclear and conventional warfare environments. Research centers on: rapid damage assessment and repair of launch and recovery surfaces for tactical and logistic aircraft; rapid damage assessment and repair of facilities, structures and lifelines; materials, methods, and equipment to limit or avoid damage to critical facilities and lifelines; accurate assessments of uncertainties which impact the survivability and reliability of systems; and the maintenance, repair and rehabilitation of worldwide real property facilities to support a high readiness level and combat sortie generation rate in a warfare environment. Individual research objectives address soil mechanics, material mechanics, structural dynamics, structure-media interaction and construction materials optimization.

6.4.1 Soil Mechanics

A fundamental understanding of the behavior of a wide range of soils is needed to relate their response to complex loading conditions. These conditions are primarily moisture content, temperature, natural formation, grain size, cementing material, intergranular structure, consolidation state and porosity. Many of the problems associated with foundation failures of structural facilities can be attributed to insufficient knowledge of the response of underlying soil layers. A fundamental knowledge of soil mechanics and its relationship to structure interaction is critically needed as a prerequisite to reduction of uncertainties in the life cycle survivability and operational adequacy of Air Force facilities.

Behavior must be understood for geologic material surrounding structures subjected to tremendous loads. Studies are required on the fundamental mechanisms and behavior of soils and other geologic materials which have a bearing on their response to internal and external stresses. Currently applied stress theories are simplified by assumptions which impair basic understanding of soil behavior. Intergranular stresses, pore pressures, porosity, soil microstructure, and how these are influenced by environmental conditions need to be studied. Appropriate parameters must be identified which can be used in mathematical analyses, and these parameters must be measured in-situ and in the laboratory. Accordingly, new testing procedures must be devised which apply realistic boundary conditions to specimens in order to measure response over a wide range of strain amplitudes and rates.

Soil constitutive models must be developed which are capable of describing the response of the soil mass to three dimensional stress/strain conditions. Unloading behavior and cyclic response over a wide range of loading rates must be considered. Saturated, partially saturated, and dry conditions must be accounted for.

6.4.2 Material Mechanics

Modern and sophisticated weapon systems place increased requirements on behavior of manufactured and natural materials such as concrete, steel, masonry, wood, asphalts, rocks, plastics of all varieties, and their composites. It is necessary to accurately predict performance characteristics and service life for those materials where they are subject to extreme loading conditions. Currently, factors of safety are usually applied in engineering practice and questions about the full working strength of the material are raised. A more appropriate approach is to be able to predict rationally the uncertainties involved in the material failure. If composite materials are used, further questions are raised on whether the full capacity of each material is being used so that stresses can be distributed equally without causing failure in one material before another.

In order to understand the basic material properties which affect stress response, representative material models or constitutive relationships are of vital importance. Theories and models should be advanced to study the fundamental behavior of manufactured and natural materials subjected to static and dynamic stress, including blast and shock. Development of reinforced concrete models which characterize response to high and low stress loadings contributed by long or short pressure durations or combinations thereof, is one of the first priorities.

The nonlinearity of geotechnical material models needs to be examined with basic mechanics principles for both the in-situ and remolded states. Material models need to be developed to represent behavior of layered systems such as in airfield pavements or slabs on elastic or inelastic foundations. An investigation into the fundamentals of how material properties influence the propagation of energy waves in layered systems is required. This research is required to advance the state-of-the-art of obtaining layered material properties and thicknesses using nondestructive testing systems which use impact loading as the input signal.

Constitutive laws for nonlinear and viscoplastic behavior must be developed to adequately represent response for materials subjected to a variety of environmental conditions associated with temperature and moisture changes, pore pressures, and geological formation. Models and parameter values should be developed to represent the thermal response of structural and geotechnical materials over a broad range of temperatures, and energy absorbing characteristics of these materials should be assessed.

6.4.3 Structural Dynamics

Basic knowledge about the response of structures subjected to dynamic stresses is required. Dynamic loads of concern are primarily associated with blast and shock from nuclear or conventional detonation, with impact and penetration from shrapnel and debris, and from acceleration effects imparted by large-mass machinery and vehicles. Numerous other nonprotective structures, either in the Air Force inventory or being projected for future facility needs, also experience dynamic stresses. These stresses are caused by wind loads, earthquake ground motions, vibrations from machinery, accelerations from aircraft engines in test cells or boosters in space launch facilities, sonic boom overpressure induced loads, and by aircraft operations on pavement.

structural systems. In order to predict behavior, performance, and service life of large structural systems, basic laws and fundamentals of structural dynamics must be established. Effects due to wave propagation need to be considered. The technologies which govern the disposition of energy on structures, the distribution of that energy through a structural element or elements, and the final stress/strain related displacement of that structure suspended in a geotechnical media, need to be examined.

Mechanisms involved in material fatigue and fracture must be related to strain rate, crack propagation, rebound, and other means of stress relief. Studies should be conducted to establish failure limits of structural materials including an evaluation of the mechanism involved in residual strength after some degree of distress.

Methods for relating material fracture and damage to facility failure and establishing techniques for stating probability of failure as a function of time, load magnitude, and load cycles are needed. A more systematic approach to life cycle survivability of structural systems must be achieved, and more cost-effective design criteria are needed. Identification of repair and maintenance techniques which can inhibit or negate distress mechanisms is necessary.

6.4.4 Structure-Media Interaction

Response models representing stress transfer between structures (deeply-buried, shallow-buried, surface) and surrounding soil media (as in the case of airfield pavements, deeply-buried systems, surface-flush facilities, above-surface facilities, and shallow-buried structures) and their mutual interaction at any interface configuration are needed. While conventional stress theories must be examined for modeling material mechanics, innovative theories, which have potential for more accurately describing real material response, need to be developed. Dynamic loadings from nuclear and conventional detonations may vary drastically in time and space. Stress magnitudes, distributions, and variations caused by soil properties and structure configurations must be quantified in order to predict resultant structural loadings and motions.

6.4.5 Construction Materials Optimization

Severe demands are made on conventional materials when they are subjected to stresses associated with nuclear or conventional weapons effects. There is a continual need for materials or composites with higher strength and toughness which can sustain airblast, thermal and shock loads to protect weapons systems from weapons effects. Conventional reinforced concrete designs will not adequately meet unique high-stress environment demands. New, cost effective materials are needed with high strength, low volume change, and rapid cure characteristics for both new construction and rapid repair applications. In addition, new knowledge is required to predict the behavior of reinforced concrete to rapidly applied loadings. Dynamic response characteristics differ significantly from those currently assumed for static conditions.

Structural behavior not only depends on material properties, but also on construction practices. Environmental climate, labor practices, design and material quality all contribute to characteristics which may be different than what was originally anticipated. As a result, methods must be developed to predict structural performance, taking into account different construction conditions and methods. Probabilistic techniques need to be developed in this regard.

Optimal behavior and structural response modes for construction materials, both conventional and advanced, need to be determined. This knowledge is basic to development of a structural optimization capability which incorporates material properties, cost, availability, threat, lifetime, environment, energy efficiency, and other relevant factors. Key needs in this development are new evaluation, test and verification methods. A related need is for new manufacturing, production and construction treatments and techniques which will improve material properties.

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SUBAREA - Environmental Aspects
of Weapon SystemsSCOPE

To maintain readiness and mission effectiveness while complying with national environmental legislation, it is necessary to establish a sound scientific basis for evaluating environmental effects of future weapon systems and AF-unique operations. This will allow AF managers to evaluate alternatives early in the weapon system concept phase, avoiding unnecessary delays in acquisition or deployment. Key research areas include generation of aircraft and missile engine pollutants, aircraft rework center waste, optical and electro-chemical measurement instrumentation, and environmental fate and consequences of AF-unique pollutants. This research is relevant to the AF Engineering and Services Center, Engineering and Services Laboratory (ESL), TPO 1 Environmental Quality.

6.5.1 Emissions Measurement and Pollution Monitoring

Research is needed to develop improved techniques for emission measurement from Air Force pollution sources and monitoring of air and water quality. New optical and electrochemical instrumentation is required which is more rapid, sensitive, reliable, and less manpower-intensive than existing techniques for measurement and identification of pollutants from aircraft engines and toxic vapors from missile accidents and fuel operations. Special emphasis is required on remote optical techniques for remote monitoring of pollutants which do not interfere with the pollutant source and reduce personnel exposure to toxic vapors. Computerized analysis systems with sensors and integrated response programming are required for real time monitoring of systems to document pollutant levels in atmospheric and aquatic environments.

6.5.2 Environmental Chemistry

Research is required to determine the basic mechanisms which control the formation of pollutants and their transport and reactions in the natural environment. Data is required on combustion reactions in turbine engines which result in increased formation of soot and gaseous pollutants. Further information is required on the subsequent transformations and environmental chemistry of these pollutants in airbase environments and their impact on air quality. Improved techniques for correlating visibility of exhaust plume with measured particulate concentrations are necessary to design processes to control emissions from test facilities and determine impacts of fuel specifications modifications. With increased pressure to use non-petroleum derived aviation fuels, research is needed to parametrically describe the influence of fuel composition on evaporative emissions, turbine engine

pollutant emissions and exhaust gas reactivity. A detailed analysis of the composition of AF jet fuels and their gaseous emission from turbine engines is needed. Information is required on fuel variability due to changes in source supplier and/or broadened specifications. More information is needed on the fuel concentrations of polycyclic aromatics and other hydrocarbons of significant health and environmental importance to allow future specifications to be formulated and assessments of fuel concentrations to be made.

Research on aquatic chemistry should emphasize AF fuels, solvents and metals used in past and present AF industrial operations and their transport and reactions in groundwater aquifers. Better knowledge of the lifetime and behavior of these pollutants in surface and groundwaters will allow rational environmental standards for emissions and effluents to be created from an accurate data base.

6.5.3 Pollution Abatement and Resources Recovery

Ever expanding regulatory requirements for control of pollution sources and emerging detoxification/destruction for hazardous waste materials are driving forces in the cost escalation of industrial waste disposal. Pollution control systems capture more emissions and associated waste materials, which add to the volume and concentration of toxics in wastes. To contain costs, innovative technologies and adaptation of evolving methods are needed to reclaim precious and strategic materials while minimizing waste toxicity, volume, and consistency for ultimate disposal.

Research is required to characterize chemical and physical mechanisms which control comingling and interactions of process by-products. Better definition of the characteristics of the unique AF pollutants will permit potential treatment processes to be evaluated and optimally designed to provide necessary control at the lowest cost. An accurate data base is needed to define reaction rates and limiting conditions for generation of toxic and hazardous by-products. Phenomena investigation into transport and degradation in the natural environment is essential. Historic operations and disposal procedures have introduced heavy metals, solvents, and petroleum products into the air, soil, surface water, and groundwater. Often these contaminants are immobilized and persist, but under certain conditions are dispersed and degrade naturally. By defining those controlling factors, input to the AF Installation Restoration Program will aid in decontamination activities. Development of detectors and sensors to locate and quantify contamination zones is crucial. (New capabilities are needed to find the fragmented needle in the proverbial haystack.) Investigation of treatment processes and decontamination techniques is needed to validate characteristics and effectiveness of potential restoration strategies. Further, development of in-situ treatment methods for hazardous materials will reduce exposure for AF personnel and the public.

A very promising new development is the incorporation of microbial populations to enhance process control and waste treatment systems. The evolving fields of microbiological conditioning and genetic engineering for fixation and degradation of hazardous substances opens a new door to treatment strategies.

6.5.4 Modeling of Pollutant Chemistry and Transport

Research is needed to provide the basis for new and improved models of pollutant formation, transport, and reaction in the natural environment. Elucidation of the mechanisms of pollutant formation in gas turbine combustion is necessary to permit modeling of the effect of engine design and fuel composition on pollutant emissions. A more accurate description of the evaporation and dispersion of toxic liquids used in Air Force operations, with emphasis on organic and gas density effects, is needed for hazard forecasting in the event of accidental releases or spills. Also, theoretically valid, semi-empirical techniques for determining worst-case ground level concentrations from vent stacks are required for toxic material storage sites. The development of methods for incorporation of pollutant reaction kinetics and the interaction of air base emissions with other pollutants in the local area is needed in order to extend the capability of current multi-source models to determine the actual contribution of Air Force operations to regional pollution.

Characterization, both experimental and theoretical, of the physical, chemical and biological interaction of Air Force-unique pollutants in air, water, sediment, and soil environments is needed. Development of models which can be used to extrapolate available data to different circumstances are essential to accurately evaluate impact of flight and ground operations. Of particular importance are analytical descriptions of the persistence of Air Force-generated toxic materials in the environment and the development of algorithms for simulating the effect of alternative control strategies for pollutants and toxic materials.

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ELECTRONICS

TECHNICAL AREA

ELECTRONIC RESEARCH OBJECTIVES

INTRODUCTION

The overall progress of military system technology depends in many fundamental ways upon electronics. Advances in materials, devices, data and signal processing techniques, and methods of increasing environmental hardness have been and will continue to be central to enhanced system performance and reduced costs. From an almost limitless range of potential areas of electronics investigation, a set of Research Objectives representing the most immediate Air Force needs and the highest potential pay-offs has been selected for inclusion in this Research Planning Guide.

It is the intent of this set of objectives to encourage innovation in areas that represent known deficiencies in the present technology base. These descriptions should not be regarded as constraining. It is axiomatic that radical and startling new ideas frequently open up entirely new approaches to the solution of operational problems. These objectives attempt to identify desired new capabilities and to stimulate innovation.

In recent years, the traditional emphasis in defense research and development on ever-expanding system performance has been tempered by an equal emphasis on reliability, affordability, and long-term supportability of end-use systems. Even when these characteristics are not specifically stressed in individual research objectives, it must be borne in mind that to be practical, a new development must be compatible with them and that new technologies specifically addressed to them are very much desired.

See also the following Project Forecast II initiatives (subarea 9.1):

PT-10 Wafer Level Union of Devices seeks to develop the technology to permit combining dissimilar microelectronic component technologies now possible only on separate, isolated, and mutually incompatible substrates.

PT-11 Photonics targets dramatic exploitation of photonic technology, based on advances in materials, wafer-level integration, and spectrally pure optical sources and detectors.

PT-14 Survivable Communications Network requires advances in signal processing and distributed information processing technologies for adaptive management of transmission resources.

PT-15 Adaptive Control of Ultra-Large Arrays requires research in adaptive control of highly distributed deformable arrays such as proposed for two additional Project Forecast II initiatives, Distributed Sparse Arrays in Space and Smart Skins.

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SUBAREA TITLE - Reconnaissance and Surveillance

SCOPE

Reconnaissance and surveillance for military purposes are concerned primarily with producing intelligence and attack alarm. Air Force operations require the search and mapping of regions of interest in real or near-real time in order to detect, identify, locate, count, or investigate weapons, personnel, vehicles, installations, lines of communication, or other features or activities by means of visual, photographic, electro-optical, microwave, electronics, and other sensing methods. Reconnaissance missions, both strategic and tactical, can in general, be divided into generic types: wide area missions such as wide area search, mapping and charting, and weather reconnaissance or specific point reconnaissance such as targeting and retargeting, weapon damage assessment, recce-strike, weather and technical intelligence. Surveillance is generally concerned with monitoring regions such as aerospace (for airborne or spaceborne vehicles and weapons) or regions on the Earth's surface (for military activities and covert penetration of defense perimeters). This RO is the electromagnetic (including optical) spectrum and encompasses both basic and applied research requirements. The capabilities of USAF to perform reconnaissance and surveillance missions in the 1980s and 1990s will depend to a large extent upon the enemy's ability to limit and negate overflights as well as to conceal targets and confuse sensors. As the enemy defenses become more formidable, the use of long range standoff sensors and sensors tailored to penetrating aircraft flight profiles will become more important. Research is needed to improve the performance of existing sensors, and new sensing concepts to the reconnaissance and surveillance inventory, and to determine and minimize the effects of the atmosphere and enemy countermeasures on the performance of such sensors at all wavelengths. The research activities must also consider and seek to optimize the human interpretation of raw or preprocessed sensor imagery, the fusion of sensor-derived product with other C³I inputs, and the impact of product quality and format on the commander's decision-making function.

7.1.1 Target Detection and Identification

Research is needed to develop improved techniques for imagery interpretation with the ultimate aim of automating the analysis of real-time, near real-time, and non-real-time sensor, ancillary, and collateral data commensurate with sensor types and mission objectives. Digital image transmission and automated screening, cueing, processing, and display concepts must be developed to allow a highly interactive mode of information transfer between the analyst and automated exploitation capabilities. Better understanding is required for the use of spectral, spatial, and temporal characteristics of target signatures in automating target detection/identification/location tasks. Capabilities and limitations of multispectral and comparative sensor utilization concepts must be examined. Levels of automation through autonomous sensor operation and imagery exploitation must be supported by the technology base. Imaging sensor display concepts must include consideration of both the display media and the visual perceptual system. Vulnerability of sensor

systems and concepts of operation to active and passive countermeasures must be established, and validated methods of overcoming these techniques must be identified.

7.1.2 Propagation and Scattering

Propagation predictions and compensation for atmospheric variations/fluctuations must be made in order to design and operate many kinds of radar systems. Knowledge of upper atmospheric densities and tropospheric and ionospheric short term (0.01 to 10 Hz) fluctuations is of particular importance to OTH radars, as is better understanding of ground screen effects. Radar and laser clutter sources such as decoys, ground, rain, and chaff must be better understood and modeled in order to support the development of optimized waveforms and signal processing techniques. Special emphasis should be placed on wide-band and bistatic properties of radar clutter. Detailed information about atmospheric propagation phenomena from UV through IR is required for the design and evaluation of both passive and active systems; atmospheric transmission, turbulence, polarization, speckle, glint, and scattering effects must be quantified, particularly over long, nearly horizontal paths and as a function of acquisition geometries, targets and backgrounds. Measurements of star field radio flux, power contours, positions, and polarization properties over the frequency range of at least 100 MHz to 15 GHz are necessary to perform space object identification radar calibrations. Polarization properties of targets, chaff, weather, and jamming must be studied in order to optimize signal processing as an ECCM technique. A better understanding of adverse weather effects, especially random phase changes induced in the return beam, is required for the optimized design and use of synthetic aperture radars. Research is required to define and compensate for multipath effects experienced by ground based radars. An evaluation of higher order scattering effects upon high resolution radar waveforms is required. The radar detection and identification of tactical ground targets using foliage penetration radar frequencies demands a better understanding of target scattering characteristics as modified by the adjacent ground and foliage covers. Research is required on the electromagnetic interactions between resonant size targets and a rough surfaced earth as well as adequate electromagnetic characterizations of foliated areas.

New methods to control radar cross-sections of conformal arrays are necessary. To control radar cross-sections of antennas, it is necessary to study the antenna as a scatterer and identify the particular scattering phenomena as a function of antenna type. This includes realization of the minimum scattering antenna in order to preserve the low observable nature of aircraft with reduced cross-sections.

7.1.3 Sensors and Sources

Space-based, optical surveillance systems require innovative research in symmetric and non-symmetric multi-element optical configurations, optical forms, multiple aperture optics, synthetic aperture optical techniques, optical countermeasures hardening, lightweight adaptive optics, lightweight controllable structures, and sensing and control technologies; consideration in all areas must be given to the dynamic and thermal environment. Electro-optical sensing and processing technologies must be advanced in order to satisfy requirements for deep space object detection and identification beyond the coverage provided by radar systems. Electro-optical and infrared detectors for both imaging and non-imaging employments must be improved in terms of their detector quantum efficiency, time constant, responsibility, uniformity, spectral response, dynamic range, nuclear radiation hardness, and bandwidth (suitable for optical heterodyne detection). Research is needed to investigate, study and analyze unique human characteristics such as odor, body chemistry, ultrasonics, nuclear spin and electrostatics which may be exploited in advanced performance human intrusion sensor systems. In addition, research is required on combined seismic/acoustic/optical/other intrusion techniques in order to make best use of unique characteristics of particular situations to enhance detection. Research is badly needed on multisensor describing functions in order to permit comparisons among imaging systems and to characterize the benefits achieved through multiple spectral band acquisition; the operator and operator/display interface must be fully considered in developing such figures of merit. New radar and other sensor concepts and techniques must be investigated in order to support the detection of very low cross-section targets at ranges sufficiently long to permit the initiation of offensive/defensive action; optical, radiometric, and radar signature measurements of such air vehicles are needed to support sensor system developments. The developmental feasibility of multispectral sensors must be investigated. Additionally, the sensor or multispectral sensor suite, to processor interface must be considered in all sensor developments. Automated processing of multispectral imagery is needed to improve the quality efficiency, and countermeasure immunity of reconnaissance exploitation. Concepts are required to integrate sensors, processors and interconnections into the skin of an aircraft.

7.1.4 Radars and Antennas

New and improved non-imaging radar techniques are necessary to permit detection, location, tracking and identification of potential tactical and strategic threats. Research is required to develop the technology necessary to perform tactical and strategic surveillance using both monostatic and bistatic radar concepts. Research leading to improved OTH antenna structure designs is required. Similarly, advanced designs are required for low profile, high gain antenna structures at HF through microwave frequencies for both ground and airborne radars. Current phased array research must be extended to develop the technology base required for the development of wide-band arrays conformal to aircraft surfaces. In the future such arrays may be required to support a multiplicity of communications and surveillance functions through electronic reconfiguration. The arrays may be part of the airframe and possess integral shields to protect from weather, EMP, lightning and physical damage. New methods to control the radar and IR cross-sections of such conformal arrays are necessary. New ways are required to form beams, monitor performance, and configure very large phased array antennas,

distributed in space or over the available skin of an aircraft. Large surveillance radar antennas will be required to operate with increasing bandwidths and lower sidelobes, and new methods and components for achieving these properties in arrays are desired. Adaptive channel equalizers and wideband array sidelobe null placement techniques are required. Better understanding is required across all aspects of radar detection of target modulated signatures, including research on the physics of vibrating metal junctions, and other modulation phenomena, if these phenomena are to be exploited for reconnaissance and surveillance purposes. Bistatic and sanctuary (standoff illumination) radar concepts must be further developed against an expanded technology base, if operational systems are to be employable in a hostile environment. Improved moving target indication (MTI) techniques are necessary to detect slowly moving ground vehicles and to reduce false alarms due to ground clutter elements. Innovative techniques and systems level analyses are required in order to achieve the integrated netting of diverse radar subsystems. Non-sinusoidal radar waveforms, such as Walsh waveforms, must be investigated in order to determine their applicability in advanced radar system designs. All aspects of radar system design, operation, and survivability must be researched in order to develop the expanded technology base required for the development of multi-mission spaceborne radar systems for air, missile and space surveillance.

7.1.5 Prediction and Recognition of Aerospace Vehicle Signatures

High frequency target signature techniques against aircraft and missiles are required for OTH radar applications including definition and concepts for the real time utilization of multi-frequency amplitude and phase signatures for resonant radar targets. Monostatic and bistatic signatures for low RCS and composite targets which use shaping, glossy materials and loading need to be developed to permit improved detection and classification of these targets. Order of magnitude improvements in radar reference parameters (geodetic, astronomic and propagation) are required to achieve a reliable capability for target hand-off between multiple space object identification radars and multiple weapon system acquisition radars.

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SUBAREA TITLE - Navigation,
Guidance,
and ControlSCOPE

Navigation, guidance, and control are functions which demand highly specialized and supporting technologies. Navigation, the process of determining position and velocity, is limited herein to automated applications in aircraft missiles and space vehicles. Engineering investigations and analyses reveal that technology has advanced sufficiently to permit multiple use of inertial navigation systems. Guidance, the process of using vehicle position, velocity, attitude, and mission data to compute thrust and steering commands, falls between navigation and control and includes Space, Intercontinental Ballistic Missile (ICBM), Anti-Ballistic Missile (ABM), Air-to-Air, and Air-to-Surface Missile (ASM) applications. Control, the process of causing a dynamic system to behave in a desired manner, as used here includes spacecraft attitude control and aircraft flight control.

Desired mission requirements are discussed for future Air Force operations. Close air support requires weapon terminal guidance techniques compatible with moving target indicating radars and forward looking infrared systems. Counter air requires self-contained integrated flight and fire control systems for air superiority fighters. All tactical mission aircraft, including remotely manned vehicles, need integrated reference and flight control systems to provide more accurate weapon delivery and greater aircraft performance options. Redundant strapped down inertial systems radio navigation integrating with flight controls can provide a control configured vehicle capability for the 1980s. Bistatic radar techniques are postulated for penetrating tactical aircraft in the 1990s to enable covert ingress and egress. Strategic offense requires accurate and autonomous navigation systems which operate reliably in severe defense threat environments. Improved strapped down sensors and radio receivers that can operate accurately in a high jamming environment are necessary to accomplish these mission requirements.

7.2.1 Laser Gyro

The laser gyro is approaching technological maturity as an inertial rate sensor. While exploratory and advanced development efforts are underway using current technology, there are numerous candidates for research in the areas of achieving ultimate performance, producibility and lower cost. Research should be undertaken to investigate (1) frequency lock and drift stability effects, (2) improved mirror performance and production techniques, (3) improved materials and construction techniques to reduce cost, temperature effects and helium leakage and simplify manufacture, and (4) integration of laser gyros in high accuracy strapdown INS configurations.

An improvement in frequency lock threshold will open up new applications for laser gyros including precision attitude reference for pointing and tracking and precision gyro compassing (1.0 arcsecond). Research addressing frequency lock and drift stability should be undertaken to (1) investigate the noise characteristics of active laser gyros to reduce noise to the quantum limit, and (2) investigate techniques for improving scale factor stability allowing subarcsecond (0.01 arcsecond) range performance.

Fundamental to the improvement of laser gyros is a better understanding of multilayer dielectric mirrors and their substrates. The substrate polishing process must be understood and quantified before the dielectric coatings and processes can be fully understood. Accurate theoretical models of the polishing process that can be used by opticians must be developed to make the polishing process a science rather than an art. Basic research must be performed in the areas of substrate surface and subsurface preparation. Concurrently, instruments must be developed to measure the results of polishing processes to verify the models.

Current laser gyro cavity construction techniques use exotic and expensive materials which are not well understood, well behaved or easily manufactured to overcome thermal expansion and helium leakage effects. Research is necessary to (1) quantify and improve current material thermal, helium leakage and manufacturability properties, (2) identify alternate materials and cavity construction techniques having lower cost, readily available, simple manufacture, well understood, and well behaved properties, and (3) develop molded laser gyro parts.

Research should be undertaken to develop improved techniques and algorithms for integration of laser gyros in high accuracy strapdown configurations for integrated navigation, guidance and motion compensation. Larger perimeter laser gyros should be investigated to satisfy the high accuracy demands of the strategic and special application aircraft.

7.2.2 Fiber Optic Gyros and Accelerometers

The fiber optic and integrated optic technology base has continued to progress as a result of development in the communications and optical electronics industries. Fiber optic gyros are capable of achieving low accuracy tactical missile grade performance but considerable effort is required to achieve the accuracy required for aircraft navigation. Improvements must be made in the thermal stability of laser sources and frequency shifters. Additional research is required in the development of integrated optic devices wherein laser sources, frequency shifters, beam splitters, and detectors are mounted on a single chip. Fiber optic interferometry may also be applied to accelerometers; so far little work has been performed in this area.

7.2.3 Advanced Inertial Instruments

There is a continuing need to improve inertial instruments by making them more accurate, smaller, more reliable, less costly, less sensitive to environmental changes, etc. As current technologies are stretched to the limits of their capabilities, future improvements must be made through the incorporation of new, exotic technologies. Piezoelectric crystal technology is now being used in low cost gyros and high accuracy accelerometers. Surface acoustic wave devices may find applications as detectors in inertial instruments. Various physical phenomena, both well known and newly discovered, should be reviewed to determine its capability to detect rotation of acceleration or to act as a detector in a more conventional instrument. New instruments will require a wide dynamic range to measure both high rates and low drift. Outputs should be digital and linear to reduce signal processing work loads.

7.2.4 Strapdown Star Sensors

Aerospace vehicles flying at hypervelocities along the outer limits of the atmosphere will require star sensors to provide autonomous updating of their inertial navigation systems (INS). Since future INS will most likely be strapdown systems, the star sensors should be strapdown as well. Research is required to develop small, highly accurate sensors for use in both manned and unmanned vehicles.

7.2.5 Molded Plastic Inertial Sensors

The need for low cost medium accuracy inertial systems is increasing as more users demand self-contained guidance systems, but the cost of machined metal sensors is prohibitive. Studies have shown that engineering plastics can be molded to finished size and shape and assembled into medium accuracy inertial sensors for as low as 1/3 the cost of conventional instruments. The cost can be further reduced through the development of innovative manufacturing processes and robotic assembly techniques. Results of recent plastic inertial sensor development efforts have shown the need to develop a plastic material whose coefficient of thermal expansion is more isotropic and closer to that of metals.

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The following topics require research attention either separately or preferably as a coherent program in order to effectively insert and realize the potential of VLSI and VHSIC technology into Air Force C³I systems:

- a. Studies which combine CAD techniques with silicon foundry chip implementations.
- b. Studies which view signal processing algorithms and architectures from the viewpoint of a single design concept suitable for VLSI implementation in the spirit of Item a. Computational techniques which are suitably married to simple repetitive architectures such as systolic arrays for parallel processing are of particular interest.
- c. Design studies in which fault-tolerance and self-test are incorporated naturally at inception.

7.3.2 Propagation Media Effects

The characteristics of the transmission path between transmitter and receiver are of the greatest importance to the communications designer, and whereas these are quite generally known for guided-wave transmission, e.g., on wires and cables, much remains to be learned for the case where the signals are radiated into extended media such as earth, water or atmosphere. This is true for essentially all of the EM spectrum from VLF to optical frequencies. Requirements for research in this area are for studies of the relationships between uniform and non-uniform, time-varying propagation media and the propagation characteristics of electromagnetic signals. Consideration is to be given to the different propagation mechanisms including partial reflection, refraction, scattering, ducting (trapping), etc., and propagation phenomena including multipath, attenuation (absorption) depolarization, dispersion, fading, scintillation, etc. Studies should be made of the intrinsic spatial and temporal variability of propagation media associated with turbulence, internal gravity/buoyancy waves, and field aligned irregularities in the ionosphere which influence the transmission characteristics of electromagnetic signals over the entire radio spectrum. For advanced adaptive antenna systems, the characteristics of the propagation media will set limits on the effectiveness of these systems. It is necessary to establish the dynamics of these processes in a turbulent, irregular medium. Suitability of millimeter waves for high data rate communications in all operational configurations should be investigated by theoretical and experimental studies of millimeter wave propagation in turbulent, refracting, depolarizing, attenuating, emitting, and bandwidth limiting media. Consideration should be given to propagation characteristics of hybrid optical/MM wave techniques for improving reliability of high data rate line-of-sight communications. Research is needed to develop reliable propagation techniques for survivable communications under the conditions of severe ionospheric disturbances such as produced by nuclear or natural, solar related events. Air/ground UHF communications links to satellites, in combination with very long range HF ducted propagation should be investigated for long-range communications system applications. Mathematical techniques need to be developed for converting measured ionospheric data into ionospheric profiles. It is critical for systems design to also know the character of the noise background. Data on the distribution and statistics of noise is inadequate and requires both experimental and theoretical studies to evaluate on

SCOPE

This subarea is concerned with Air Force Command, Control, Communications, and Intelligence. This involves the technology for managing Air Force resources in a stressed environment. It includes the collection, transmission, and processing of military information for planning and execution of military operations, with emphasis on survivability, timeliness, security, and reliability. Specifically, it includes technology associated with adaptive, survivable communications, distributed data processing and data bases, rapid intelligence exploitation and automation.

7.3.1 Signal Detection and Processing

Modulation and detection processes are central to a large segment of military communications. The continued transition from analog to digital communications has introduced a multitude of new problems. Efforts should be continued in the development of new modulation and detection techniques that will improve performance with high speed data (megabits/second) while improving spectral efficiency. High performance must also be obtained under jamming, intercept and deception threats. Controlled redundancy for error correction (coding) improves performance and provides ECCM. Wideband techniques such as spread spectrum are actually based upon coding concepts. The technology for integrating and implementing simultaneously both demodulation and decoding should be pursued. Detection and tracking of multiple targets, via M-ary hypothesis, in a dense noise and clutter environment is becoming a system requirement for an increasing number of missions. Attention should be given to sequential algorithms which stop the arithmetic operations when a specified level of performance has been achieved. Such algorithms allow the computational capability to be available for other system functions. Another topic which should be studied is the use of signal processing techniques in a microwave cross polarization environment to enhance signal discrimination. Also, the application of code division multiplexing to spread spectrum communications signaling merits investigation. In millimeter wave communications, the modulation techniques for digital millimeter waves are spectrally inefficient, and alternate routing techniques need to be explored for use in highly congested areas or in jamming environments. Modulation techniques such as adaptive equalization (decision feedback and deconvolution) and interference reduction is also an ongoing requirement. The use of optical or integrated optical techniques to perform signal processing at RF should be explored. Correlation of target dynamics along with a priori information such as "track before detect" techniques should receive considerable attention.

Replacing analog filters and equalizers by digital, special purpose computer type arithmetic units promises reduction in size, weight and cost, and better adaptability in long distance data transmission and multiplexing applications. A similar approach may replace the filter elements in analog transmitters, receivers, and signal amplifiers. Research should be continued to explore synthesis procedures and performance.

devices for visible and infrared wavelengths; (b) sensitization techniques for holographic materials to permit use at greater ranges of wavelengths; (c) techniques for fabricating high efficiency holographic optical elements; (d) improved holographic materials which will record at long wavelengths with high diffraction efficiency; (e) three-dimensional holographic techniques; (f) computer generated holograms, and (g) phase only holograms.

7.3.4 Electronic Encoding/Decoding

The first task in communications and imagery transmission is often to prepare the signal for transmission by compacting it so as to minimize capacity requirements while giving due regard to fidelity and reliability. In particular, the outputs of sensors, video information and imagery require the application of data compaction techniques. Low-bit-rate speech over an all-digital circuit is required as well as speech processing and digitization to reduce bandwidth while maintaining speaker recognition. Low-bit-rate imagery communications is required for efficient delivery over existing communications media. Techniques for encoding speech signals, which are essentially one-dimensional time processes, have included direct digitization (PCM), differential digitization (Digital Delta Modulation), frequency selective digitization (channel vocoders), frequency adaptive digitization (format vocoders), run-length encoding, and predictive encoding; all of these techniques can be used to achieve a degree of efficient source encoding. Although some of the techniques of speech processing can be applied to sequentially scanned imagery, its two-dimensional nature readily lends it to two-dimensional transform techniques for source encoding. Thus, it may be possible to more readily and efficiently apply known data compression techniques to the resultant two-dimensional arrays of imagery transform (Fourier, Bessel, Walsh, etc.) data. It is possible, moreover, that combinations of direct and transform imagery data compression might be more effective than exclusive use of either. In the area of voice encoding, research is needed in the application of Automatic Speech Recognition for speech bandwidth compression under limited vocabulary constraints; it has the potential of being the most efficient source encoding technique for real-time voice communications.

For real channel communications, encoding/decoding is one of the techniques for matching the information signal to the channel transmission characteristics to obtain required link and network throughput characteristics; a wide variety of block and convolutional coding theory and practice is available for application. The effort that is needed is research on decoding algorithms and structures which are programmable over a wide range of code parameters to avoid the proliferation of techniques that result when each source-channel-sink combination is treated as a unique problem. An additional benefit from programmable decoders is adaptivity to changing conditions in the channel, especially in multiple signal, multiple jammer scenarios. Noting that spread spectrum sequence codes are a special case (very large redundancy) of coding against a "noisy" channel, consideration should be given to the possibility of combining spreading and coding algorithms and the possibility of finding means of direct transformation from signal space to information space.

a global basis. Powerful radio signals can modify the ionosphere through non-linear processes, and the effective use of this technology in communications and surveillance requires new work, both theoretical and experimental. Numerical simulation techniques are required for propagation in artificially modified ionospheres in order to achieve reliable electromagnetic transmission of military information. This will provide a better understanding of properties of the polar ionosphere in which many Air Force systems must operate, provide real-time ionospheric corrections for existing operational systems, and greatly improve existing techniques for system simulation and diagnosis in the presence of ionospheric irregularities. The ability of particle beams in space to generate electromagnetic waves and to modify the ionosphere for enhancing or degrading propagation offers the possibility of a new, non-conventional radiation technique. Theoretical studies of the radiation mechanisms and propagating modes should be conducted leading to a demonstration experiment.

7.3.3 Imagery and Holography

Many command and control systems could be vastly improved with the introduction of image or 2D information. This is largely due to the fact that the fastest form of information input to a decision maker is through his visual system. The demands for greater image resolution in the strategic arena and for real-time availability in the tactical arena will continue to push the state-of-the-art for many years to come. This calls for a great deal of innovative research in imaging and image processing from the sensors to the information display systems. For example, in the area of imaging or image sensing, it would be highly desirable if techniques could be found that would yield optical-type resolutions for longer-wavelength all-weather systems. Imaging reconnaissance is a primary source for targeting strike and intelligence data. Schemes are being sought that will permit 2D transmissions through aberrating media so that image information could be communicated even in the face of declining weather conditions. Optical processing techniques are needed that will be capable of performing a multitude of real-time operations on images such as de-blurring, level slicing, image compression, motion estimation, edge detection, and feature enhancement. The trend in reconnaissance sensor development has been and will continue to be toward digital systems with real-time or near-real-time sensor output. The Air Force capability to convert this output to intelligence for use in command and control is directly related to the ability to detect, identify and locate targets of interest in a timely manner. Efficient pattern recognition and automatic target recognition techniques for real-time display (as well as improved image compression methods and enhancement) are required to bring processing/analysis rates in step with collection rates. (See Section 7.1.1) Of equal importance is the utilization of all available sensor data, coupled with collateral data, to allow for more complete and exact portrayal of static mobile and moving ground targets in tactical and strategic situations. Also, the use of phase correlation techniques for comparing sensor images with stored reference pictures as a means of route following and terminal navigation for cruise missiles is a concept which merits continued investigation.

Research in holography will contribute to the real-time processing of images as well as other areas such as non-destructive testing and evaluation, high storage density memories, improved topographic mapping techniques, and large format displays with high brightness and resolution. Particular research emphasis should be given to the development of better real-time hologram recording

format and linkages, inferential rules for intelligence data bases, and any other pertinent technical considerations which impact the processing of data in an accurate and timely manner.

A comprehensive, well-integrated and easily understood theory of security related to automated information processing systems needs to be developed. The theory needs to incorporate mathematical models of compromise, integrity and denial of service, and has to include use of software tools and techniques to formally demonstrate that complex systems correctly implement a stated policy in an unsubvertable manner. The models, tools, and techniques must be applicable to both single and distributed processing systems.

Studies investigating computer designs that more directly execute HOL programs are needed. Emphasis should be placed on architectures suitable for physically smaller machines (i.e., exploiting VLSI and VHSIC technologies) used primarily in a dedicated manner for real-time applications as opposed to designs more suitable for large, multi-user, multi-processor systems.

Research is required in microprogramming and virtual machine technology as a tool to facilitate software transportability and system design verification. Research is needed in High Level Hardware Description Languages, retargetable compiler techniques and the use of virtual machines to support simultaneous operation of multiple machines. In a related area, research is required in the use of emulation in support behavioral system simulation. Those levels of simulation then need to be integrated into a total hardware/software system design methodology.

The rapidly changing hardware available to the system designer has complicated the design processes. New tools are necessary, especially for the design of functionally partitioned systems. Partitioning techniques which will allow for dynamic task allocation in multiple processor systems and enhance system fault tolerance are required. Approaches to incorporating recent hardware fault tolerance concepts into Air Force systems should be devised. New methods are needed to accelerate the generation of system simulations so that such factors as processor activity, intercommunications, and memory utilization can be examined in the context of complex problem and execution.

Much work needs to be done on signal processing architectures utilizing inexpensive parallel processing elements rather than the current pipeline architectures. Conceptually, what is desired is hardware configured to address the "corner turn" problem of two-dimensional processing and at the same time able to increase bandwidth by simply adding another processing module. Software must be transparent to the addition of the processing module. The program must be in three interlocking phases: (a) the architecture needs to be developed, (b) the operating system software must be developed, and (c) the higher order language which will make the architecture transparent to the user must be developed. All three of these efforts should be interlocking. In particular, as we approach the DoD standard language, i.e., Ada, it is imperative that signal processing instructions be incorporated in it (e.g., array and vector operations, corner turning, etc.) so that further proliferation of higher order languages will be avoided. Furthermore, studies investigating computer designs that more directly execute HOL programs are needed. Emphasis should be placed

7.3.5 Computer Software/Hardware

Software Sciences Technology is concerned with the data processing requirements for the design, development, and optimization of high speed, high capacity information processing systems, and associated support software, to provide effective, real-time support to the Air Force's mission. The rapidly growing cost of software requires continued research to find more productive and reliable methods for developing software. Research in the areas of advanced higher order programming languages and software engineering is required and should include the development of efficient compilers, integrated programming environments, knowledge-based systems, and technique/tools for life-cycle testing/verification/validation, quality measurement, and cost estimation.

Research is needed in the area of Automatic Programming to develop practical systems that automatically generate routine programs for a minimal input specification or are able to automatically perform major modifications on existing programs. Ultimate long-term orientation should be to handle inputs from non-professional programmers in a loose format, context-free environment. Immediate results, understandably, will have more rigid constraints. Current philosophy ties the principle of this field closely with those of semi-automatic, assertion-oriented program verification. However, an impasse as to the size of permitted programs appears likely; as program size increases, the theorems and proofs of the theorems grow exponentially. Therefore, alternate methods to those that currently exist are necessary for automatically generating and proving theorems for large-scale programs. Also, for the automatic generation of programs, research is needed in theoretically defining and specifying the semantics of data and the semantic operation of computer programs, and in formally specifying the functional requirements the system must fulfill.

Techniques are required to provide an "expert assistant" interface between the user, the systems programmer, and the computer for the development of systems for interrogating large data bases, evaluating sensor data, and/or planning and allocating resources. Such interfaces will allow rapid response to changing mission requirements without the need for extensive reprogramming or even the intervention of a programmer, and also facilitate the response to unexpected questions. Research is needed in systems based on artificial intelligence techniques that are capable of developing the complex interrelated structures of factual knowledge, processes, and user requirements that allow the user to interactively and automatically structure a system that will provide the required responses and permit the utilization of the computer in a collaborative manner rather than as an adversary.

Data base systems function as repositories of data, data collectors, data communications, data organization and storage processors, and information retrieval and display systems. These functions should be coordinated to ensure effective, efficient, and economical operation of the total system. In its primary function as a repository of data needed for strategic, intelligence, or tactical data processing, the data should be accurate, private, protected from damage and organized so that diverse users (with different data requirements) can utilize it. To do this, research should be emphasized in data base management systems, distributed data bases, high level interfaces, data

upon architecture suitable for smaller machines used primarily in a dedicated manner for real-time applications as opposed to designs more suitable for large, multi-user, multi-processor systems.

Technological developments have impacted modern warfare to the point of surpassing our abilities to effectively manage it. The speed, power and sophistication of modern weapon systems and surveillance/collection systems, plus the political and geographical diversity and complexity of potential battlefields, have placed military commanders and their staffs at the receiving end of massive amounts of data which is often incomplete and/or conflicting. To improve the overall effectiveness of tactical commanders and their staffs, decision aids must be developed for selected critical problem areas using powerful information aggregation and interference techniques to improve accuracy and consistency in the stressful and changing battlefield environment. The decision aid developments will be based upon advances in decision analysis, artificial intelligence and operations research technologies and will assist the decision maker by taking him beyond the burden of analyzing data with standard data manipulation and display techniques.

7.3.6 Distributed Computer Architecture

The evolution of circuit technology has made it feasible to interconnect multiple computers in both high bandwidth local networks and lower bandwidth geographically dispersed networks. This has the potential of providing greater flexibility and thereby increasing survivability. Network designs that allow comprehensive testing, simple maintenance procedures, and strong error control mechanisms are needed. New design methodologies which take advantage of advanced software design, implementation and test techniques must be developed to include distributed system primitive operations as constructs. The ability to multiple heterogeneous computers to communicate over a network is well within the state-of-the-art. However, to effectively utilize the resources at the various nodes of the network, research is required in the area of resource sharing. Some productive results have been obtained in dealing with homogeneous sets of computers; however, the technology does not currently exist to handle the heterogeneous sets. For many years, the attributes of load leveling, survivability through dynamic reconfiguration and better crisis response through dynamic priority allocation, have been postulated for computer networks. None of these will be possible until the capability to dynamically allocate and share resources at the various nodes can be achieved. This implies a large set of research problems in the area of protocols, data migration and synchronization, job migration (with and without data), distributed operating and file systems, restart recovery procedures and many others. Solutions to all these problems are required before a resource sharing distributed data processing system can be achieved. Effective methods of interconnecting networks must be developed to accommodate multiple protocol sets. With the emergence of multi-level secure operating systems for individual hosts, techniques must be developed to incorporate multi-level security constructs into distributed systems. This must include the development of new security models to accommodate multiple "sub" models for individual hosts as well as protocol verification between the hosts.

7.3.7 Remote Electronic Control of Aerospace Vehicles

Research should be undertaken in the area of signaling structures as they relate to the generic problems associated with digital data links for the remote electronic control of aerospace vehicles. The multiplicity of data link functions and platforms associated with the variety of missions involving remote electronic control and the generally hostile environment in which these missions are conducted require more efficiency from the modulations employed. While current bandwidths and data modulations are generally acceptable, the current approach to employing separate, discrete techniques for source encoding, error encoding, synchronization and anti-jam spread spectrum should be improved through more efficient modulations which can couple signal processing functions and reduce implementation requirements. The spectrum utilization of the modulation should be more efficient. That is, the system should possess low sidelobes, be able to be filtered and limited without reconstituting the sidelobes, have a constant envelope signal, and provide a high energy density in the intended transmitted bandwidth. Extremely rapid synchronization/acquisition of the spread spectrum signal is becoming more critical as the velocity and dynamics of the platform and the ECM threat are continually increasing and burst communications is becoming more necessary to accommodate multiple access requirements. In many cases, the signaling structures must not contribute to decreasing the covertness of the radiating terminal. Furthermore, the modulations must be adaptable, allowing for real-time tradeoff between signal processing capabilities--in particular, between data rate and anti-jam performance and between numbers of users and different instantaneous mixes of data rates. The signaling structure, therefore, has emerged as a most critical item in deciding the viability of remote electronic control concepts. Improvements in both transmit and detection properties of the signaling are needed. Finally, RPV control links require high performance antennas with significant ECCM capability. There are needs for adaptive null steering arrays for both the RPV and the multi-function command and control terminal antennas.

7.3.8 Secure Aerospace Communications

There is a need for studies of signal structures for satisfying integrated functions of communications, navigation and identification (CNI), and research is required to optimize switching, multiplexing and handling of voice, wideband data and spread spectrum waveforms.

Communications to satisfy the needs of real and conceptual systems are directed, in the first place, toward much greater use of digital techniques. Digital systems must provide great signal reliability, which can be enhanced by error coding, and they lend themselves most readily to encryption, thus providing greater security for the information they transmit. Digital techniques can provide multi-function performance, and they can ease problems of compatibility among different communications systems provided considerable work is done to develop the technology and standards needed for flexibility for transmission. Requirements for digital information over common facilities. All aspects of communication must be survivable under the most adverse conditions, which calls for the development of the equipment reliability as well as robust signals. The future must be able to develop resistant concepts using filtered and encrypted data links to provide secure networks of distributed assets. The future must be able to develop time and space consistency, and the system have

limited survivability; therefore, further exploration is needed. Alternate approaches such as surface redundant millimeter radio wave communications or waveguides (including fiber optics) should be investigated to identify and develop suitable technology. Many systems will utilize or will be supported by technology that is derived from research in the area of communications. The research thrust should be in specific communications technology areas to satisfy future systems as well as overcome some of today's deficiencies.

An increasingly important aspect of communications is the need for increased signaling rates, improved reliability (signal/noise ratio), increased survivability and interference rejection; antenna array techniques have been widely used to provide improved signal/noise ratios and interference cancellation, but at the cost of reduced bandwidths. The current research in phased array signal algorithms is intended to simultaneously achieve wide bandwidths and spatial selectivity. The long term objectives of work in this area include: (1) Improved bandwidth capability for a given physical antenna structure with prescribed gain and cancellation capability; (2) Improved convergence rates for arrays with large numbers of elements and reduction of convergence rate sensitivity to signal level, interference, antenna geometry, and waveforms; (3) Simplification of sample matrix algorithm solutions; (4) Optimized integration of frequency domain (spread spectrum) and space domain (adaptive antenna nulling) techniques; and (5) Incorporation of spectral estimation to enhance array spatial resolution.

A second technology which will greatly improve the survivability of Command and Control Communications is routing schemes which can adapt to dynamic network conditions. The network congestion is the result of man-made or enemy-induced network anomalies, such as node destruction or trunk jamming, or excessive traffic over high usage trunks. A routine scheme must be capable of adapting its "normal" procedures to select alternate routing paths. These strategies must be coordinated with the current status of equipment and network performance status with appropriate information being delivered to the various management levels to permit a timely response. Only under such a routing strategy can critical and transitory command and control information reach its final destination, i.e., at least one path between source and destination exists. Furthermore, in addition to research on such adaptive routing techniques, system and traffic control procedures must be introduced in our network designs so that the information required by an adaptive routing scheme is available at a node. In this manner, nodal information will be available so that a path selection may be made. These procedures must be carefully studied for the purpose of selecting optimal strategies as a preliminary to the selection of engineering designs. An item related to automation is the technical control of command and control. The initial effort has been completed to produce such a system for controlling today's analog communications system. Technology is now available to make real-time measurements and assessment of the performance of the tactical communications systems now being installed. Means are needed to separately identify and measure the equipment performance and the path performance.

1.3.4 Mission Analysis and Evaluation

The C² process is based upon the dynamic interaction of command and control communications and the assets within the war environment. The war environment is a complex system of interacting elements and processes that must be understood in order to provide a basis for the development of a C² system.

available assets. The C³I orchestration required is highly dynamic and varies within and between missions being performed. This variation causes detailed interaction between participants to be constantly varying to meet changing environmental conditions. In light of these requirements, the C³ system must provide the capability to sense the system needs, distribute this data base via communications systems and correlate various inputs to provide feedback to decision makers (battle managers or command authority) on the changing environment. Once this is accomplished, the decision maker can reallocate assets via communications systems to appropriately close the sensor/action control loop process.

Understanding all the ramifications of such a process required that many known scientific disciplines be integrated into a new field of knowledge entitled C³ analysis. This new field of knowledge is based upon mathematical principles of adaptive system control, communications, cueing, estimation and decision processing theories. Further, this new field of knowledge must be developed in a form to allow software coding to be developed into a system simulation capability. This simulation package shall be based upon the use of a number of levels of simulation all related back to the operational problems at hand and the military doctrine. These various simulation levels shall be driven by the system level force on force modeling and provide data base in proper form to allow detailed element as well as technology simulation to be conducted. This multi-level simulation approach limits computer run time while providing insight into the problems to be resolved. The most important part of the simulation process is providing a means to validate simulation through correlation with a dual field testing. Once the validation process has occurred, the impact of proven technology or sensor concepts can be measured by system simulation from an operational viewpoint.

Throughout the research and development cycle, modeling and simulation acts as a common analysis vehicle for identifying C³I capability enhancements. Specifically, it improves/increases our capacity to understand and trace problem issues through a top-down "System Approach" to requirements delineation. Concepts must be developed, evaluated and validated before modifications are implemented. Technology capabilities and limitations must be determined prior to purchase. Detailed designs must be evaluated and validated against total system configurations. Test plans are developed to measure the effectiveness and performance must be tested against its impact on specific theater C³I system environments and tailored to meet its individual requirements.

The need in this technology area is to not only determine the mathematical models to understand the C³I process, but also the means to evaluate concepts or technologies through computer modeling. The models employed should use statistical methods as well as time event driven deterministic design approaches. Most important is the need to accurately model the operational threat environment as well as weapon system effectiveness. The role of the decision maker within this dynamic environment is a central problem which must be evaluated and modeled. Once these complex interrelationships are defined, sensor, communications, correlation, and decision feedback characteristics of C³ systems can be analyzed under stressful conditions to define and provide systems enhancements.

7.3.10 Artificial Intelligence

The increasingly complex and extensive information emanating from today's sophisticated Air Force defense system overwhelms our abilities to react accurately and in a timely manner in critical decision situations.

Artificial Intelligence (AI) research focuses on endowing computers with the ability to perform tasks judged to require perception, reasoning, and learning. Machine automation of these basic human capabilities would enable Air Force computers to assist in the speedy solution of complex, unstructured problems. There is an AI technology base available that can be exploited for Air Force applications and there are many other C³ applications which require the technology of AI, but which cannot be satisfied on a practical basis by the current state-of-the-art.

Research is needed to fashion software tools that enhance human decision-making performance. Such aids will need to be functionally flexible, near-real-time responsive, and user adaptive to unforeseen circumstances in decision situations that include tactical mission planning, target aggregation, electronic fault diagnosis, automatic system reconfiguration to recover from battle damage or subsystem failure, equipment maintenance, senior battle management, situation assessment, and hardware design and testability.

AI research to provide advanced hardware and software support for the sophisticated information processing requirements of dynamic situation assessment is necessary. The intelligence analyst is confronted with ever-increasing amounts of real-time data from increasingly complex sensor sources. An Intelligent Analyst System must be developed that will continuously synthesize new information into possible competing scenarios of adversary intent and action, evaluate the new observations in the context of existing scenarios, and, where necessary, resift prior data to establish a credible interpretation for new observations.

Additional investigations must shift the majority of the routine responsibility for software life cycle management to the computer. Central to this goal is the concept of a knowledge-based software assistant, an interactive software tool that will serve as both the corporate memory and as a knowledgeable junior programming assistant throughout the life cycle of design, production, and maintenance of large Air Force software packages.

Research is needed to create flexible, adaptable, multi-media man-machine interfaces that will become standard requirements of future Air Force C³I systems as the advanced technology to support a more "people oriented" interaction is developed. A common core C² interface of this nature will provide tactical commanders a transparent communications channel across all C³ systems.

The primary goal of Air Force applications of AI is to allocate information processing and decision functions between man and machine in a way which optimizes use of their respective strengths and weaknesses. Basic research in areas of knowledge acquisition, representation, integration, and utilization supporting this primary goal must be increased.

Automated target recognition equipment is required to solve specific Air Force problems in the mission areas of Reconnaissance, Surveillance, Intelligence,

7.3.11 Fault Tolerant Architecture

Research is needed to develop and validate techniques for designing fault tolerant digital processors. The need is particularly acute in space systems. The advent of LSI/VLSI technology offers the possibility of significantly increased circuit complexity within weight and power constraints of aerospace vehicles. Redundancy, automated fault isolation, watchdog supervision, and other fault tolerance methods can be applied at all levels of a system, down to the individual integrated circuits. Architectural concepts, analytical methods of evaluating fault tolerant designs, and practical implementation procedures must be developed before this enhanced reliability can become an operational reality.

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SUBAREA NUMBER 2.4

TECHNICAL AREA - Electronics

SUBAREA TITLE - Components

SCOPE

The research objectives of this subarea encompass a broad spectrum of basic electromagnetic phenomena, device concepts, and components underlying the potential application of electronics and the exploitation of electromagnetic materials to meet future technological needs of the Air Force and to prevent future technological surprises in military electronics and avionics. It also outlines research necessary to develop technology for the improvement of reliability, radiation hardness and the ultimate availability of electronic components and systems. More specifically, research in this subarea is concerned with the detection and controlled modification of electromagnetic signals by means of: materials, science, and engineering studies of unique and special properties of matter in the gaseous or condensed state; theoretical and experimental investigations of electronic, magnetic, optical, acoustical, thermal, and mechanical properties of selected crystalline and noncrystalline electromagnetic materials grown, prepared and processed in special ways; and fundamental studies to provide the basic understanding need for determining electrical and physical mechanisms which effect device performance, data recording/processing techniques, and techniques for the generation, modulation, propagation, absorption, reflection and alteration of electromagnetic energy. Research objectives in this subarea seek to provide the Air Force with a strong, broad scientific base for the exploratory development and engineering design of novel and superior electromagnetic devices, components and systems. Research on modern electromagnetic device concepts and components has significant potential impact on such Air Force functions and operations as: detection; surveillance; reconnaissance; command, control, and communication (C³); navigation and guidance; Identification Friend or Foe (IFF); intelligence gathering; weaponry; and counter-measures.

2.4.1 Microwave and Millimeter Wave Solid State Devices and Circuits

Research and development is required to increase the power, efficiency and frequency capabilities of microwave and millimeter wave devices for applications in radar, electronic warfare and communications. Needed efforts include theoretical and experimental investigations of materials properties, both bulk and thin film, hall effect, and other hot electron effects; properties of compounds, heterojunctions, semiconductors with and without modulation doping, new device concepts, both diodes and transistors; materials synthesis and fabrication techniques; submillimeter wave fabrication techniques; integrated circuitry; and other novel power generation schemes, and other related research to demonstrate wideband impedance matching and power combining, efficiency, and capacity. High power control devices such as modulators, phase shifters, and regenerative devices, especially in the millimeter wave band, form the major part of the effort. Low loss passive components require effort in high frequency. Materials for increasing the saturation speed of semiconductor devices, in part of future devices are required. Interest in low power, wide band integrated circuits with very high speed is expected to increase with the computer with frequency, emphasis on the millimeter wave region, and the development of the integrated circuit technology. Power

concentrate on the physics of new interaction schemes and the development of device designs for specific applications. Foremost in this research should be the establishment of suitable technology and analytical techniques for the required electron beams. Although distinguished by the great simplicity of their interaction circuits, the fast wave devices place demands on beam technology and analysis which far exceed those in the more familiar slow wave devices. Once the feasibility of a new interaction scheme is determined, a practical assessment of its applicability must be made, to include voltage requirements, beam control requirements, magnetic fields, and other device characteristics. One specific area of research that is needed for the support of high power microwave and millimeter wave tubes in the field is a practical vacuum sensor that can be built into a tube initially and then addressed periodically throughout the life of the tube to determine whether the vacuum supports reliable operation.

1.4.3 Integrated Optics and Fiber Optics

Fiber optic communications offer many advantages such as higher capacity, lighter weight, smaller size, and reduced susceptibility to electromagnetic interference.

Many practical fiber optic component problems must be solved prior to operational acceptance of the technology. Some generic problems for military applications are: operation over the military environmental range (e.g., temperatures), high reliability, nuclear hardness, and reasonable cost. Some specific problems are: optical sources which are hermetically sealed and have high power output with efficient fiber coupling; low cost, low loss fibers; high performance detectors which are radiation hard; field installable connectors with low, reproducible insertion loss; and reliable fiber optic cable under aircraft conditions. All of these areas require considerable component research, even though fundamental feasibility has been shown.

Transmission at 1.1 - 1.6 micrometers over silica optical fibers offers important advantages of lower attenuation, dispersion and radiation sensitivity. Silica optical components enabling operation in this wavelength range are based upon the material system of InP and its alloys. Current growth technology includes liquid and vapor phase epitaxy, metal organic chemical vapor deposition, molecular beam epitaxy, and implantation. Development of high quality InP and its alloys is essential for the realization of low loss waveguide, isolator, and detector.

Millimeter wave integrated circuits are still in the early stages of development. The technology is currently limited by the lack of suitable low loss, high power millimeter wave components. The development of millimeter wave components is a major task for the next several years. The development of millimeter wave components is a major task for the next several years. The development of millimeter wave components is a major task for the next several years.

Research in several areas is required to enhance the performance of integrated optics technology. There is immediate need for low loss optical waveguides. Present losses in planar waveguides (1-5 dB/cm) make low level signal applications extremely difficult. The scattering losses mask the signal and limit the dynamic range of the integrated optics circuit to sometimes unacceptable levels. In addition, low loss stripe or ridge waveguides must be developed for routing information throughout a substrate for applications such as optical interconnects between devices on a substrate or possibly between chips. Losses need to be reduced by a factor of 1000.

The long-range topics of interest in integrated optics are concerned with materials and the potential for optical processing devices such as bistable optical devices. Present integrated optical circuits (IOC) are hybrid in nature and are mechanically aligned and held together. To achieve a truly integrated circuit, the circuit must be constructed on a single substrate. Two of the more promising materials for monolithic approaches are GaAs and silicon. Both materials must be evaluated to determine whether others the most capability and the limitations involved. The alternative to the monolithic approach is the hybrid approach presently used. Improvements in this direction of different materials on a single substrate must be evaluated and whether or not the inherent processing advantages of the monolithic approach is further weighed to the degree of technological improvements that can be made in the hybrid approach. If the approach is to be used, the material selection, the processing, the packaging, and the testing must be carefully considered. The monolithic approach is a long-range topic and is a subject of continuing interest.

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to power dissipation per operation and to increase frequency response. To meet this goal, significant lithography advances will be required to deep UV, x-ray, electron beam and ion beam techniques. Improvements are necessary in: (a) High resolution pattern transfer techniques to replicate submicrometer sized patterns, (b) the deposition of specialized thin metal films and dielectrics for single and multilevel contacting and isolation, (c) more sensitive and controllable positive and negative resist polymers, (d) techniques for low temperature shallow implant and anneal steps, and (e) techniques to increase device dimensional accuracy and to improve packing density.

III-V and Silicon Devices - Emphasis must be placed on the study of submicron devices and the modeling of such devices. Hot electron effects and possibly ballistic effects become of importance and need to be studied. Silicon devices on insulating substrates should be investigated. Of importance also is the realization of nonvolatile memory structures for both signal and data processing and mass storage. Novel device structuring may be obtained with low temperature techniques, such as molecular beam epitaxy and laser induced epitaxy of polycrystalline silicon films.

III-V and Silicon Devices - Submicron gate length devices become of increasing interest for integrated circuits due to their excellent performance. Areas of interest is the study of submicron devices, where ballistic and hot electron effects are predicted. Another area of interest is the study of heterostructure devices which exhibit improved carrier mobility. Novel device structures such as the permeable base transistor and the insulated gate transistor need to be studied to determine their performance characteristics for use in submicron integrated circuits. Devices made of III-V compounds and other III-V compounds, including heterojunction structures, should be emphasized. Novel material processing techniques such as molecular beam epitaxy and organometallic deposition, low temperature processing, and the performance of devices built in these materials need to be studied. Surface and layer boundary characteristics greatly affect the performance of devices and controlling and screening surfaces and interfaces are of great importance. The passivation of III-V devices is of great importance and the study of these structures should be investigated.

Optical and Electro-Optical Techniques

Optical devices are required to be able of functioning inside the submicron regions and are required to be able of functioning in micrometer regions and are required to be able of functioning in millimeter regions. Electro-optical non-linear devices are required to be able of frequency conversion for submicron regions and millimeter regions with wide spatial area. Optical devices are required to pass or block selected wave-lengths of light and to be able of functioning on demand. Research in optical and electro-optical techniques will assist in meeting the requirements for submicron, millimeter and micrometer materials and techniques. The study of optical and electro-optical damage is of great importance.

Optical and Electro-Optical

Optical and electro-optical devices are required for free-space communication and for micrometer and millimeter regions. In the millimeter and submillimeter region, the baseline requirements for materials and techniques are based on new phonon-terminated materials and techniques.

Of particular interest are materials which are tunable over large spectral regions, flashlamp pumped for good lasing efficiency, damage resistant, and without excited state absorption. In the near-infrared to mid-infrared spectral region, the GaAs family of lasers, lead salt lasers, Ni: MgF₂ and nonlinear conversion techniques such as optical parametric oscillation, Raman conversion and frequency doubling or mixing offer wavelength agility. It is desirable to study lasers of these generic types to obtain compact, tunable solid state lasers in the indicated spectral ranges. New techniques such as phase conjugation, optical parametric amplification and fluorescence conversion need to be considered for ways to dramatically increase the available output power of solid state lasers. More advanced coherent tunable sources, such as free electron lasers, should be investigated for long term applications which require small size and high performance.

7.4.7 Gas Laser Techniques

Research support is required in the area of chemically and electrically excited pulsed gas lasers in spectral regions from 0.35 to 5 micrometers and in the 10.6 micrometer region. Pertinent gas lasers include rare gas halide excimer lasers, metal vapor lasers, metal halide dissociation lasers, hydrogen halide chemical lasers, high pressure rare gas lasers, and CO₂ lasers. Research in the area should specifically address laser efficiency and lifetime problems. Some of these lasers have a very high operating efficiency, which has not been exploited and most of them have problems relating to long and reliable operating lifetime. The following research areas are suggested for the study of either efficiency or lifetime problems, or both:

- a. Novel plasma excitation techniques - Study of high frequency, microwave, capacitively coupled discharges or similar approaches for the benefit of electrodeless laser excitation. Detailed studies of plasma parameters for these discharges should emphasize distribution functions, E/N, kinetic sequences, excitation rates, power loading, efficiency of laser state excitation, containment evolution and discharge chemistry.
- b. Gas preionization techniques - Study of radioactive tracer gases, x-ray preionization, dissociation due to preionization, influence of preionization on contamination, and kinetics of preionization.
- c. Electrode phenomena - Study of the chemistry of the discharge relative to electrodes, study of catalysts and catalytic converter electrodes, and study of the evolution of laser gas contamination.
- d. Kinetics of laser plasmas - Theoretical and experimental studies of excitation cross-sections, laser excitation paths and their kinetics, excited state absorption cross-sections, quenching rates and cross-sections, recombination rates of diatomic or triatomic molecules, distribution functions, and excited state densities. Modeling of vapor, excimer and dissociation lasers with the inclusion of excitation circuit parameters is perceived to be especially relevant.

7.4.8 Signal Processing Components and Systems

Advanced signal processing components are needed for many emerging system applications ranging from voice compression to processing high resolution radar data at full instantaneous bandwidth. Baseline technologies must be established for single chip devices capable of real-time processing of substantially increased arrays of data. It is clear that several critical areas must be addressed in digital and analog processing techniques and

technologies if future avionics and C³ needs are to be met. The problem area involved in very large scale high speed integrated circuits are: (a) Testability - as VLSI density increases with reduced geometry, testability on and off chip becomes a very significant problem; (b) Fault Security - on chip architecture and interconnection between chips, as well as software architecture, must be given very serious consideration if reliable signal processing systems are to be provided for future requirements; (c) Flexibility - VLSI chip architecture, interconnectivity techniques, and control techniques all must be considered so that signal processing configurations can be altered in static/adaptive/dynamic ways; and (d) Design Capability - techniques that reduce initial investment and time required to produce a design must be developed. Research is needed in all technologies that have good potential for advancing that state-of-the-art in these areas.

For specialized signal processing applications at ultra high speed and/or very large volumes of data handling, optical in conjunction with digital methods need to be investigated. Special emphasis on high dynamic range optical components and methods and high speed electronic-to-optical and optical-to-electronic interfaces need to be developed. Components, materials, architectures, interconnects, and miniature size structures require research to realize the ultra high processing speed potential of optical methods using both time and spatial techniques.

7.4.9 Surface Acoustic, Optical, and Magnetic Wave Device Components

Microwave acoustic and magnetic wave devices are required in many military applications for use as compact, reliable, solid-state microwave components such as dispersive and nondispersive delay lines, tapped delay lines, encoders, decoders, filters, amplifiers, harmonic generators, mixers, detectors, convolvers, filters, phase shifters, and acoustic waveguides. The size and weight reductions possible with these components make possible such airborne applications as target identification and acquisition by radar, information processing, airborne surveillance, fuses in advanced missiles, and false-target generators in electromagnetic warfare. However, these devices, many currently in the laboratory prototype stage, required considerable research before their full potential can be applied to military needs. Research on the interaction between EM radiation and solids, electro-acoustical effects in solids, and acoustic and EM propagation in solids must be pursued and exploited to properly support technology in this area. Research on new launching techniques, the reduction of insertion loss and the careful determination and control of "second order effects" is now required. Materials having high piezoelectric coupling coefficients combined with good temperature stability (now mutually exclusive attributes) are needed.

Research on generating integrated passive acoustic and magnetic wave devices with circuits on GaAs and InP base materials at UHF and microwave frequencies is required to develop chips with very large signal processing throughput. Research on aging mechanisms of SAW oscillators offers the possibility of compact stable clocks at UHF. Electronically variable time delay units are required for beam steering in wide instantaneous bandwidth phased arrays.

Microwave acoustic devices are capable of unprecedented time bandwidth products and would provide capabilities for secure communications systems and pulse compression radars unachievable by any other practical means.

7.4.10 Frequency Control Devices

The timing and synchronization needs of military systems rely almost entirely on precision frequency control devices. These devices are generally categorized as crystal oscillators, atomic/molecular frequency standards, and optical resonators. There has been a dramatic increase in the level of precision required for frequency and timing applications. Several requirements exceed the capabilities of state-of-the-art technology. The application of high-speed electronic technology to digitized communication systems, for example, has produced combined specifications of frequency stability, warm-up time, size, weight, and cost which require substantial advances in each of these characteristics. Other environmental demands such as the ability to withstand vibration, abrupt gravity changes, and extremes of temperature and humidity call for fundamental improvements in the understanding of the physical phenomena controlling device performance. In the case of quartz oscillators, emphasis should be placed on improvement of thermal and mechanical stability of the resonator by study of the stress-compensated (SC) cut and an analytical search for other potentially beneficial cuts. The characterization of noise sources in oscillators should be improved with the goal of increasing signal purity. Fundamental studies of the quartz material can provide improvements in aging rate and possibly the warm-up time problem. New techniques in atomic and optical frequency standards should be emphasized in an attempt to reduce the high cost of these devices, a factor which has limited severely the scope of their application. These include optical state selection/detection methods, studies of approaches to reducing the size and weight (and therefore cost) of atomic/molecular frequency standards, and analysis of novel systems for possible use as primary or secondary timing devices.

7.4.11 IR Detector Array Technology

The need for IR sensor technology is particularly critical. Requirements exist for high resolution, high sensitivity detector arrays which will improve signal-to-noise ratios, spectral agility, and system range performance in the entire spectral range from 0.1 to 40 micrometers.

Current infrared systems typically use scanning optics and a very limited number of detectors which are individually connected to amplifiers. Methods are needed to develop technology for batch fabrication of arrays of detectors with the required signal processing devices to eliminate the bound on detector number which is set by the individual interconnect requirements. These Integrated Focal Plane Arrays (IFPAs) of detectors offer the potential of greatly increasing the number of detectors per system, which will increase the sensitivity and resolution of IR systems. A diverse technology base is required to address the wide variety of application problems found in Air Force IR systems. Staring, high uniformity, high operating temperature arrays are needed for terminal guidance applications. Staring IFPAs require photo-response uniformities better than 0.3% for 3-5 micrometers thermal imagery that is free of fixed pattern noise. Other requirements such as wide field-of-view threat warning systems will need scanned, very high sensitivity, low resolution arrays of optimal but diverse spectral sensitivity, and other requirements such as FLIRs and reconnaissance systems will require very high angular resolution, high total (pixels) resolution, and very high sensitivity. These requirements will cover the IR spectral band from 2 to beyond 20 micrometers. Integration of the detector arrays with signal processing on the same IC chip should also lead to improvements in system costs, reliability and simplicity.

Research is required on material and material growth methods to realize the optimized device structures (such as quantum well devices) and performance. Investigations of detector and electronic read out structures that enable very high dynamic range signal detection are required. Materials, structures, devices and architectures that provided increased signal processing on a focal plane array and that are compatible with automatic target recognition and artificial intelligence processing concepts are required. The high density architectures must be compatible with high data rates, high dynamic range signal handling and processing.

1.4.12 Antennas and Associated Components

Antenna development needs are comprised of numerical analytical methods as design tools, airborne and spaceborne antennas, and adaptive interference rejection techniques.

Radio microwave physics research in scattering, antenna radiation principles, and the propagation of EM waves in complex media is required for the evolution of new radiating systems for radar and communication applications. Although present analytical and experimental techniques are adequate for the analysis and control of the scattering properties of isolated metal objects, new techniques are needed to handle diffraction from extended rough surfaces, scattering from objects imbedded in glossy surfaces, and scattering from moving or turbulent media. Analytical techniques that incorporate modal analysis, geometrical theory of diffraction, and singularity expansion methods for the design of antennas and arrays are needed which incorporate aircraft environmental effects in such a way that antenna interelement coupling and element placement are precisely accounted for and antenna performance thereby becomes predictable. Similarly, analytical techniques are needed for determining the interaction of the antenna with single and multiple frequency radomes and with other conducting portions of the aircraft surface for widescanning arrays.

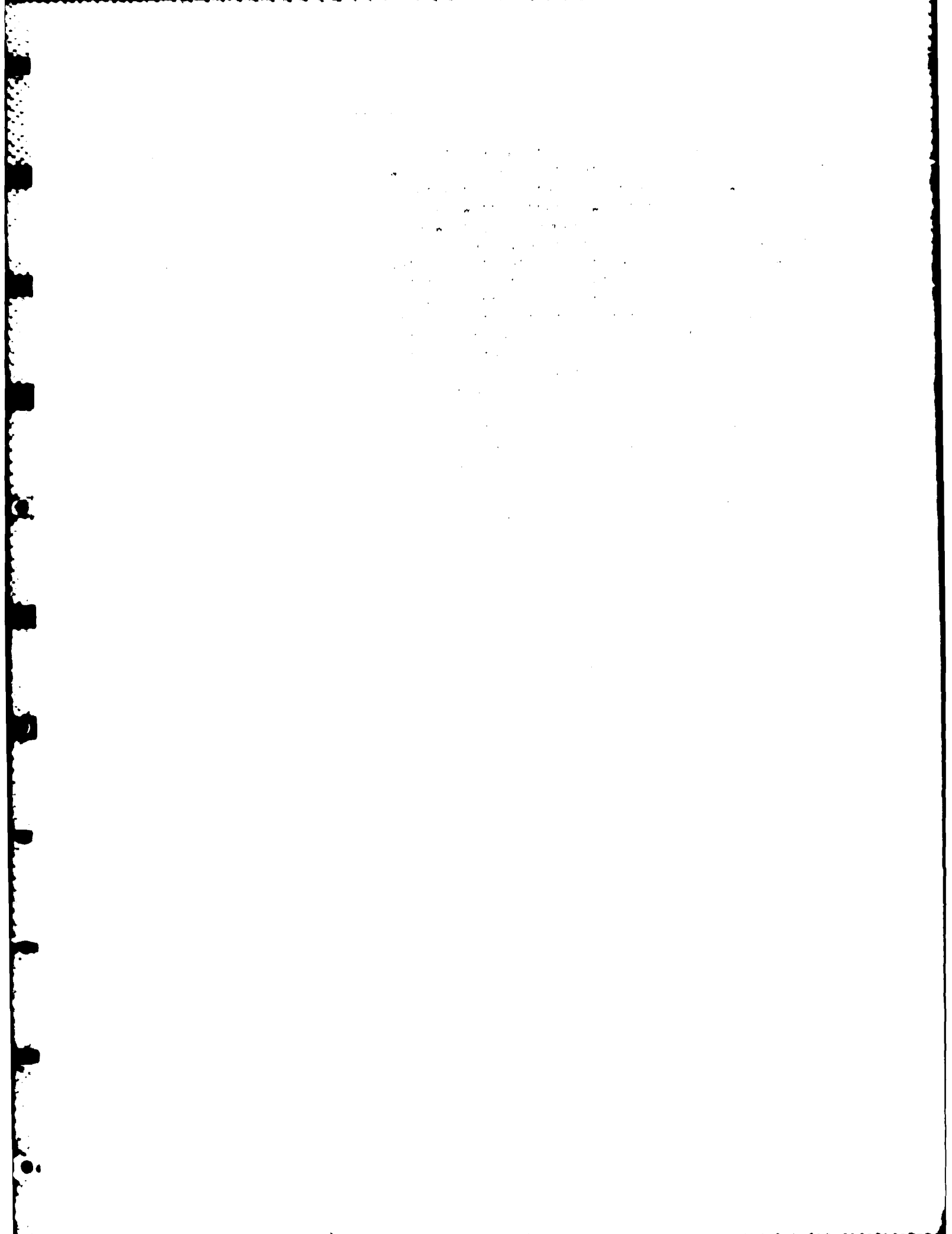
There are requirements for improved antennas and antenna scanning systems for both ground based and airborne surveillance and communication systems. Functional systems wherein problems exist or are postulated include C3, RPVs, satellite communications, radar, ECM, and EECM. Because of the advantages of operational diversity and increased reliability, emphasis is being placed on developing solid state, multifunctional phased array antennas. All related components such as TR switches, phase shifters, etc., require refinement before they will be available in highly reliable solid state form. The principal solid state phased array problem which inhibits operational system implementation is cost; monolithic ICs circuit development with increased yield is required as a potential cost reduction technique. Multifunction phased array applications are being addressed wherein one or more octaves of bandwidth with polarization diversity are required. There is a need for studies of phased arrays that are constructed and mounted in such a way that they conform to the curved surfaces of typical aircraft wings and fuselage and, in addition, present a low radar cross section. For such arrays that occupy a relatively large portion of the aircraft surface, the effect of surface flexing on the antenna radiation pattern must be determined for precision low sidelobe antenna applications. Microstrip and other forms of transmission line/antenna technology should be investigated, to achieve low profile, adaptive, and high gain scanable phased array antenna systems. Future efforts should investigate extending microstrip techniques to the larger scanable phased arrays with operation at troposcatter and SATCOM

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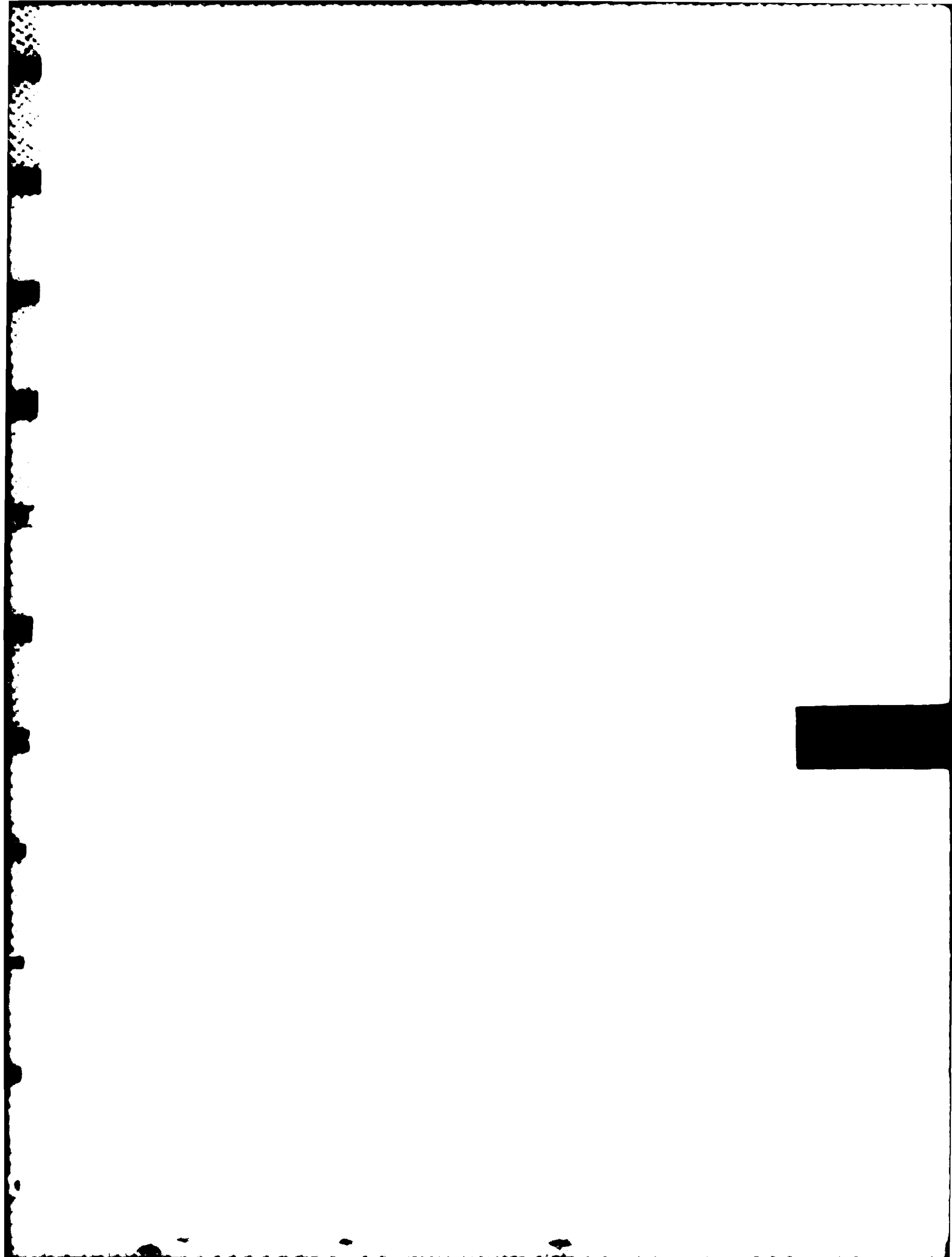
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...and the *Journal of the American Medical Association* (JAMA) has been the most widely cited journal in the field of medicine for over 100 years.



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- 8.4.7 Approximate Models for Control of Distributed Parameter Systems

SCOPE

This subarea supports research that leads to innovations and improvements in the conceptual design of computers to fulfill Air Force needs. One part of the investigation examines the possibilities and problems that arise in using various degrees of parallelism in computers. Strictly serial and massively parallel structures form the extremes, but understanding of intermediate structures, and of reconfigurable and adaptive architectures is needed. These issues are closely related to questions that arise in dealing with networks and hierarchies of computers that may be close or remote. For example, techniques for assessing network reliability are essential for efficient and secure functioning of decentralized systems. Distributed systems offer the potential of increased reliability and greater processing capacity than single processor systems. Emphasis in this area is on discovery and understanding of fundamental algorithms that can execute on networks of asynchronous, communicating processors and on finding techniques for avoiding or detecting deadlocks. Another important question is how computers with missions of active elements can be made tolerant of the defects that occur. At least in the first few years the chips with micron-sized components may have a significant fraction of defective elements. Closely related questions involve self-diagnosis and self-repair in computers. The nearly infinite possibilities of VLSI require special methods for efficient layout and mask design. Techniques of graph theory and artificial intelligence show promise in greatly speeding up the process.

8.1.1 Computer Architecture

Studies investigating computer designs that more directly execute High Order Language (HOL) programs are needed. Emphasis should be placed on architectures suitable for physically smaller machines (i.e., exploiting VLSI and VHSIC technologies) used primarily in a dedicated manner for real-time applications as opposed to designs more suitable for large, multi-user, multi-processor systems.

Research is required in microprogramming and virtual machine technology as a tool to facilitate software transportability and system design verification. Research is needed in High Level Hardware Description Languages, retargetable compiler techniques and the use of virtual machines to support simultaneous operation of multiple machines. In a related area, research is required in the use of emulation in support of behavioral system simulation. Those levels of simulation then need to be integrated into a total hardware software system design methodology.

The rapidly changing hardware available to the system designer has complicated the design processes. New tools are necessary, especially for the design of functionally partitioned systems. Partitioning techniques which will allow for dynamic task allocation in multiple processor systems and enhance system fault tolerance are required. Approaches to incorporate recent hardware fault tolerance concepts into Air Force systems should be devised. New methods are needed to accelerate the generation of system simulations so that such factors as processor activity, intercommunications, and memory utilization can be examined in the context of complex problem and execution.

Much work needs to be done on signal processing architectures utilizing inexpensive parallel processing elements rather than the current pipeline architectures. Conceptually, what is desired is hardware configured to address the "corner turn" problem of two dimensional processing and at the same time be able to increase bandwidth by simply adding another processing module. Software must be transparent to the addition of the processing module. The program must be in three interlocking phases: (a) the architecture needs to be developed, (b) the operating system software must be developed, and (c) the higher order language which will make the architecture transparent to the user must be developed. All three of these efforts should be interlocking. In particular, as we approach a DOD standard language, i.e., Ada, it is imperative signal processing instructions be incorporated as this language is formed (e.g., array and vector operations, corner turning, etc.) so that further proliferation of higher order languages will be avoided. Emphasis should be placed on architecture suitable for smaller machines used primarily in a dedicated manner for real-time applications as opposed to designs more suitable for large, multi-users, multi-processor systems.

8.1.2 Fault Tolerant Architectures

The evolution of new generations of computers makes it clear that the traditional sequential computer architecture will soon be overtaken by newer architectures featuring multiple processors. This thrust is being enhanced by technological advances, especially in VLSI, and there are growing problem areas involving the most effective ways to exploit the new chips. Research is therefore needed into architecture innovations, especially those that contain interconnecting multiple processors. Several types of such systems are already emerging, and can be classified according to the degree of integrations and processor granularity. As examples, there is the processing cell with no memory such as a VLSI chip, and the processing element with memory, such as the multi-micro computer system used as a signal processor. Both of these are closely integrated, whereas in local area networks and long-haul networks, the integration is loose, and the processors are mini-or micro-processors or the main frame computer, respectively. Research is required in the area of fault tolerant design, specifically how to use the interconnection structure as a basis for fault tolerance. Also needed is research in fault tolerance in VLSI arrays. The usefulness of these arrays cannot be fully realized until techniques are found that can execute arbitrary

algorithms on these arrays. Another serious problem is yield, which becomes worse as circuit density grows. Incorporating redundancy for fault tolerance can provide a practical solution to the yield problem; one circuit can often be accepted in spite of a fault by means of restructuring.

8.1.3 Computer-Communication-Networks

Multiple access computer communication networks are being used increasingly to provide reliable flexible distributed telecommunications and processing services. With the advent and introduction of low cost sophisticated microprocessing modules, the development of network design and analysis disciplines has become an urgent requirement, especially for applications in C³I. For tactical warfare the concept of packet radio networks with large measures of redundant repeaters, promises a degree of survivability and reliability never before achieved. Most computer communication networks incorporate multiple access communication channel systems, which are shared among the network stations. The formulation and analysis of efficient access control policies and flow and congestion control strategies are of great importance in the design and evaluation of multiple access networks.

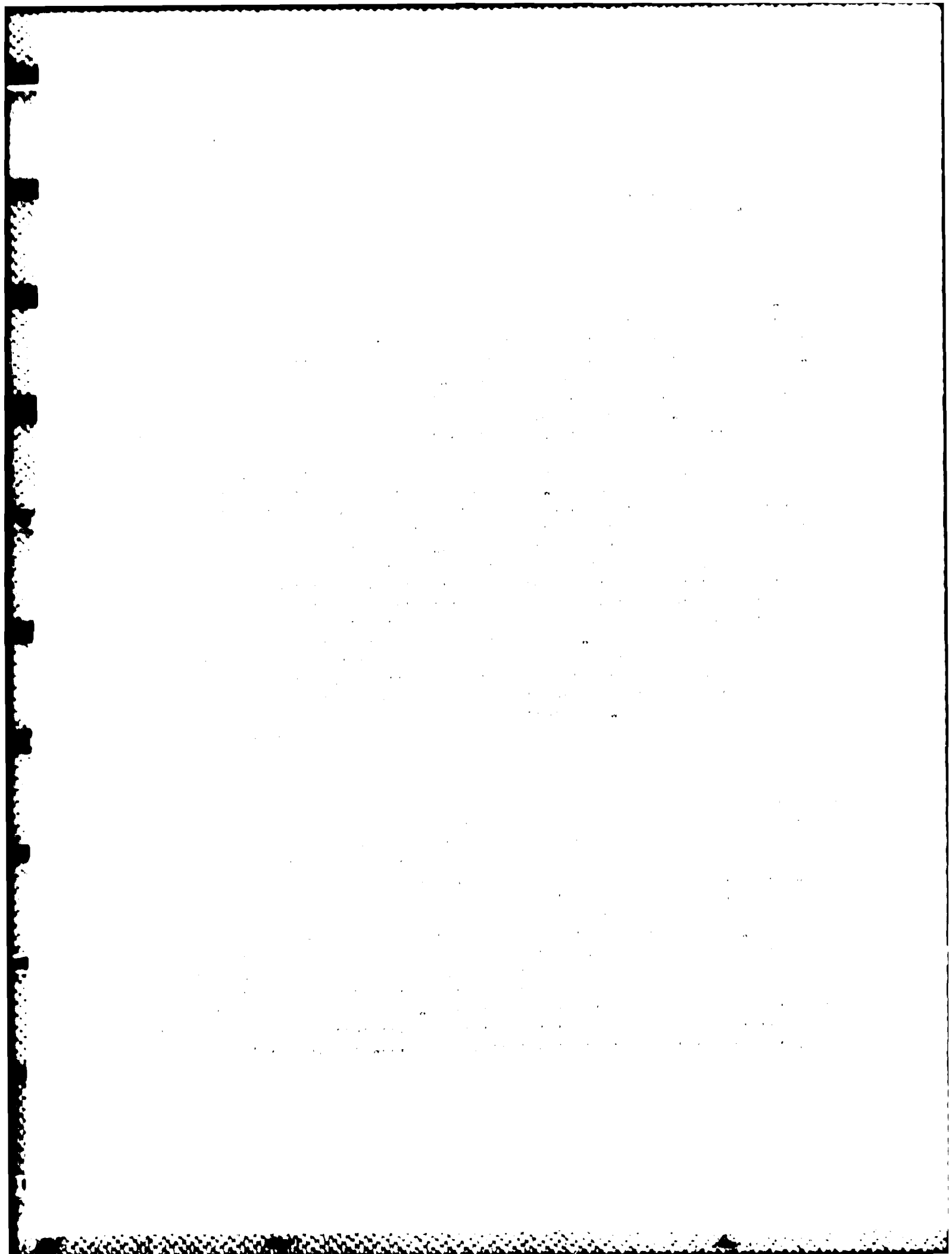
The two most common access control disciplines for the control of shared multiple access channels are the fixed-assignment TDMA (time division multiple access) and FDMA (frequency division multiple access) schemes. In the TDMA scheme, each network station is allocated periodic time slots during which it can transmit its ready messages, using the entire channel bandwidth. This type of discipline allows considerable flexibility in providing multiple access communications to diverse information sources, and is therefore widely used. Under the second scheme, the FDMA scheme, each station is allocated a dedicated frequency band. Limited to this band, a station can continuously transmit its ready messages. This type of discipline is expensive to implement and is accordingly also widely used. These two methods are best for cases where the traffic is steady. Other schemes are used where traffic is of a bursty, low volume type. Random access and polling schemes provide efficient control in such environments. At medium traffic levels, reservation schemes are very effective. Here, ready stations transmit first a reservation packet which tells their needs for channel transmission service. Transmission slots across the channel are then allocated according to these requests. The assignments are made on first come first served or on a priority basis.

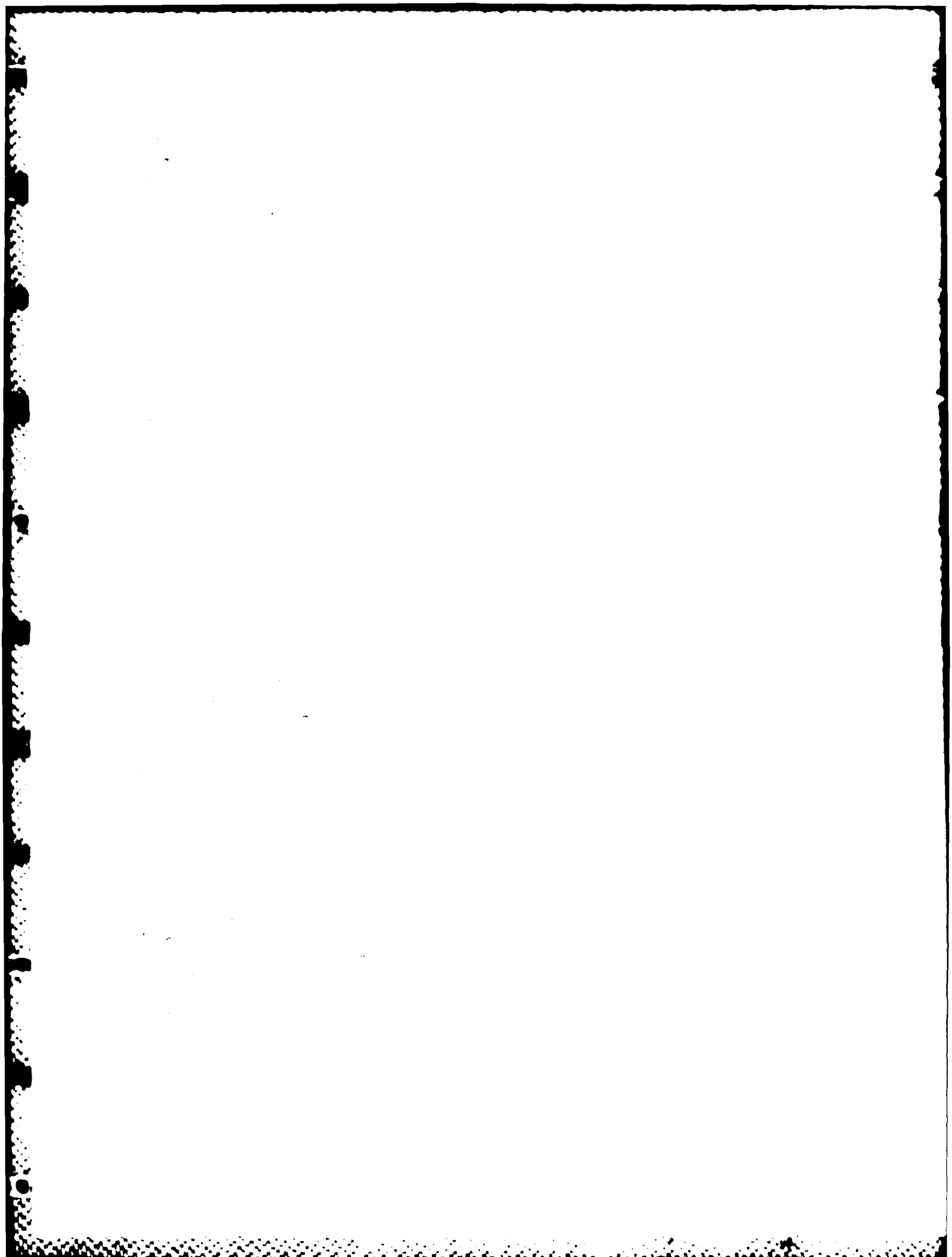
Research is needed in message delay analysis for priority based TDMA, FDMA and reservation schemes for multi-access networks, performance evaluation and control of dynamic random access and hybrid multiple access schemes, performance analysis of polling and adaptive polling schemes, congestion control and flow control systems employing admission control, local, area, and local area network architectures and protocols for the integration of data, voice, and video.

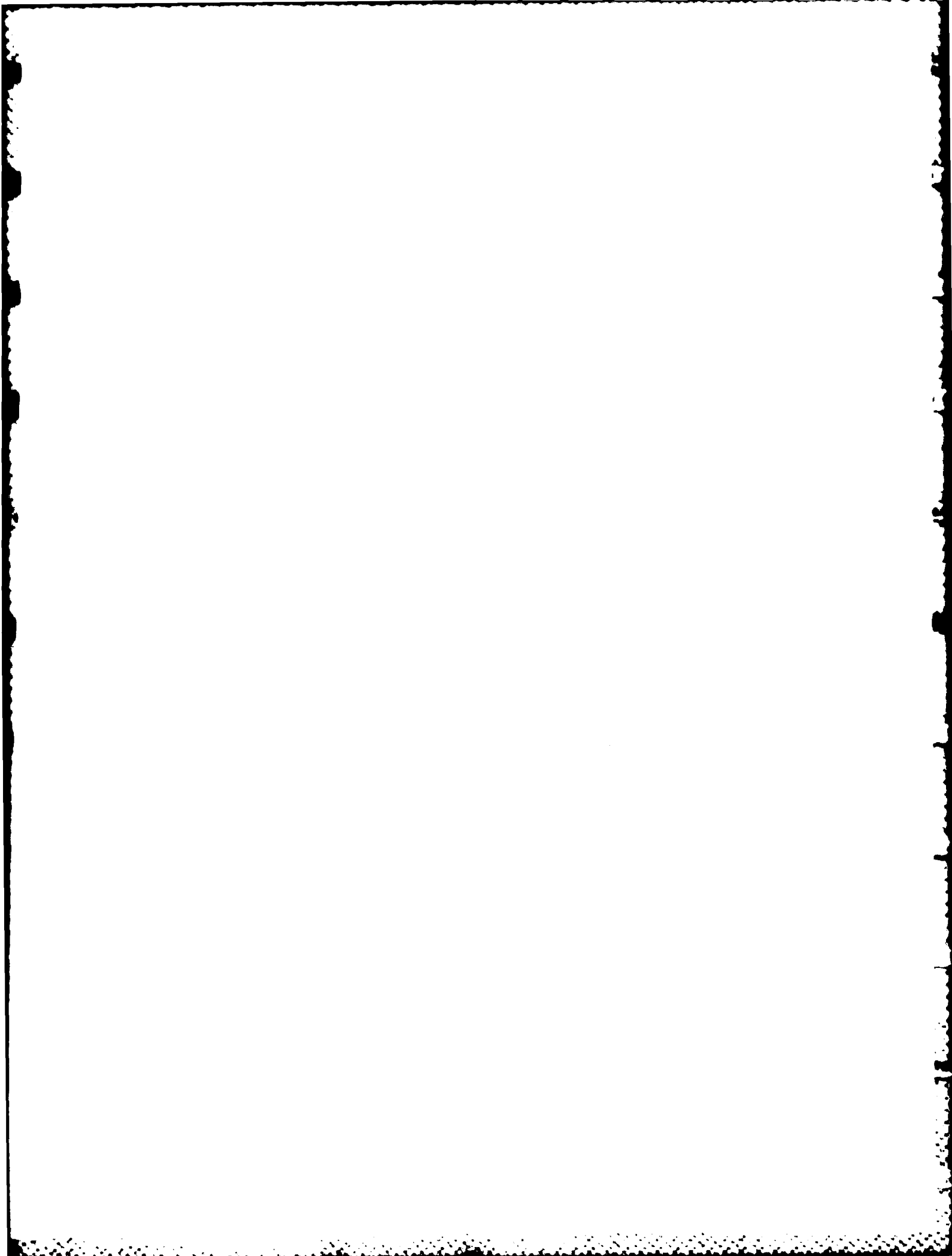
The computer is a machine that can be programmed to perform a wide variety of tasks. It can be used to store and retrieve information, to perform calculations, and to control other machines. The computer is a very versatile machine and can be used in many different ways. It can be used to help us in our work and in our lives. It can be used to make our lives easier and more convenient. It can be used to help us learn and to help us grow. The computer is a very important machine and it is one that we should all know how to use.

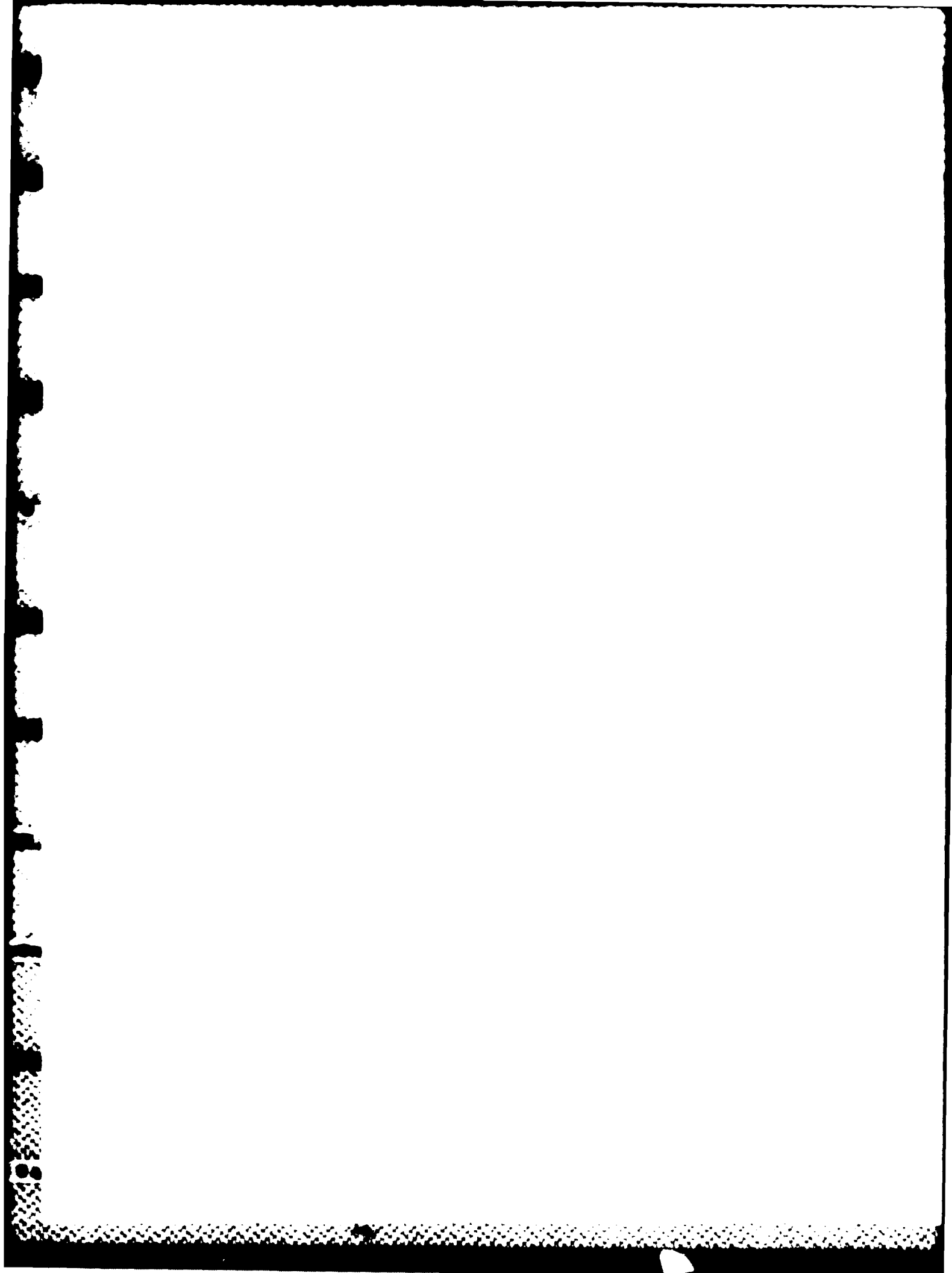
software engineers to help them deal with the data processing requirements for the design, development, and integration of complex, high-capacity information processing systems, and to provide support software to provide effective, continuing support to the Air Force community. The rapidly growing cost of software requires that new approaches be found in more effective and reliable methods for developing software. Research in the areas of advanced higher-order programming languages and software environments is required and should include the development of software compilers, integrated programming environments, knowledge-based systems, and techniques for life-cycle testing, verification, validation, quality measurement, and cost estimation.

The first of these is the *Journal of the American Medical Association* (JAMA), which has been the most influential of the medical journals in the United States since its founding in 1883. It is a weekly publication, and its content is primarily focused on the latest research and clinical practice in the field of medicine. The journal is published by the American Medical Association, which is a professional organization of physicians in the United States.









of the use of digital filters in communications systems, signal processing, target identification, or parameter estimation applications. Digital filters are used in control systems, adaptive filters for line prediction, predictive speech systems, and seismic analyses. The classic work of Wiener and his theory of prediction and smoothing. While the traditional work in this area is concerned with stationary processes, recent work has treated certain types of nonstationary processes. A typical problem is to obtain faster algorithms without losing accuracy or numerical stability. For several types of problems, fast algorithms have been developed that permit huge masses of data to be analyzed in a fraction of the time that older methods would have required. Further research is needed to extend the autoregressive modeling results to the case of autoregressive-moving-average models, extension to the situation of poles on or very near the unit circle, parallel and pipe-lined implementations of the generalized lattice filters, and the study of the approximation properties of the lattice filters. In adaptive filtering, additional work is needed to understand the steady-state output error due to finite precision arithmetic. In steepest-descent algorithms the step size has to be chosen carefully to achieve convergence, but the older analyses assumed exact computations; when the arithmetic is finite precision there are additional constraints on the step size which if not satisfied, will cause the filter to stop adapting prematurely. The goal is to achieve fast filters with modest precision and acceptable accuracy. Another topic requiring research is systolic structures for VLSI implementation of digital filters. In some of the structures proposed recently only 25 percent of the hardware is busy at any given time.

4.4.2 Decentralized Systems

In large scale systems, including military, engineering, and business organizations, there are often complicated decision problems where conflicting requirements have to be met and enormous calculations and computations are needed. A single objective optimization procedure cannot capture all the aims of such a decision procedure since the decision makers with conflicting goals who do not agree on a single objective. In addition, there may be a hierarchy of decision makers which cannot be ignored in any mathematical model. One area of research for treating such problems is the theory of games, especially the Nash and Leader-Follower problems. The theory of games dictates the decomposition of large problems into smaller problems which are coordinated in some sense. The problem of decomposing large scale systems which are components of a larger system is a topic of current interest. The dynamic equations as well as the states of the components are coupled to the states of other systems. The theory of decomposition is usually not complete, and further work is needed in mathematical modeling.

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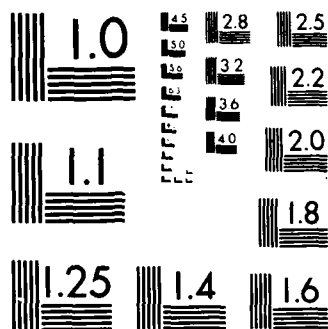
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equations for the description of the time evolution of the systems, noisy state observations with delays, and memory of previous decisions for the information, plus cost functionals. Although most real problems are nonlinear, the difficulties present even in the linear models in a game structure will probably dictate that research be concentrated at first on the linear models.

8.4.3 Computation of Reliability for Complex Systems

Evaluation of the reliability of complex systems is critical to the secure and efficient functioning of communication networks, aerospace vehicles, and many other systems of Air Force interest. These problems often involve prediction of system reliability from component reliabilities, and in the base of network reliability, are NP-hard. A continuing research goal in this area is the reduction of computational complexity in these problems and the development of efficient algorithms to implement complexity-reducing schemes. When considerations of maintainability and availability are needed, reliability problems, even for fairly simple systems, become analytically intractable and computer-based modeling is essential. Realistic models that take into account such features as imperfect repair and component dependence need to be developed and validated for use.

8.4.4 Computer-Intensive Statistical Procedures

Statistical procedures requiring large-scale computing capabilities have been rapidly developed in the past few years. These procedures include resampling schemes (bootstrap, jackknife); cross-validation techniques; robust procedures for censored data; graphical representation of large data sets, with applications to pattern recognition; the estimation of probability distributions from partial knowledge of their Fourier transforms; Bayesian approaches to quality control and reliability growth; enumeration and classification of experimental designs; and the analysis of queueing networks. These techniques can greatly improve inference capabilities with less sensitivity to departure from assumed distributional forms. Their development and use will require improved methods for handling and displaying very large data sets (especially high-dimensional data) and the adaptation of large-scale statistical computing to small-scale, real-time computing environments, including the development of interactive analysis capabilities for semi-automatic exploratory data analysis.

8.4.5 Models for Numerical Calculations (Floating Point)

A very important aspect of effective computation is a thorough understanding of the behavior of solutions of the mathematical systems that describe adequately the real nonlinear properties of physical, chemical, biological, and engineering phenomena. To know the nature of a solution is the essential first step toward its computation. The needed understanding can

be attained only by penetrating analysis of the essential features of nonlinear algebraic, differential, and partial differential equations, inequalities, and variational principles. The required research in the analysis of nonlinear systems should take advantage of small and large scale experimental computation which simulate such systems or which deal with special models in which properties such as chaos or multiple bifurcation appear especially accessible. When such experimental testing is performed by the originator of the computational algorithms, a substantial improvement in the research ensues. This combined analytic-numerical experimentation approach to the problems of interest in the sciences, engineering and mathematics should greatly enhance the understanding of these problems.

Engineering problems include distributed control systems, control system with delays, possibly chaotic flutter problems, possibly non-unique transonic flows, plasma solitons in microwave tubes, as well as key aspects of large codes such as those supporting the aerospace industry, like grid generation, graphics display, and algorithm testing. Nonlinear effects like solitons in long chain molecules, flame stability, and oscillatory chemical reactions as well as improvements to aspects of classical techniques like Hartree-Fock are problems in chemistry.

In physics the problems include optical feedback instabilities, break-up of convection patterns in large aspect ratio fluid system, the self focusing singularity of the nonlinear Schrodinger equation and "statistical" time series tests for deterministic aperiodic flow (weak turbulence) discriminating between the random and the chaotic. Simulation of biosynthesis of enzymes, population processes, and crystal and molecular structure determination are important problems in the biosciences. In the above the predominant, but not exclusive, research goal is the improvement of the computational system.

8.4.6 Models for Non Numerical Calculations (Symbolic and Fixed Point)

The use of mathematical techniques has historically involved extensive creation of symbols. The manipulation of such symbols is not a well-developed science. As computers have become more accessible many of the tedious manipulations have been programmed. This has drawn attention and research interest to the combinatoric problems associated with the exponential growth with problem size of symbol storage requirements and computation time for many of the classical algorithms. Effective symbolic computation is an area of research that needs considerable work. General purpose symbol manipulators benefit from computer architectures having a large uniformly addressable memory and optimizing the efficiency of certain elementary operations. Inexpensive personal computers satisfying these requirements can be expected in just a few years. Thus it is important to consider the insight to be gained in exercising existing symbolic capabilities on prototypical problems chosen to support the interests of the sciences, engineering, and mathematics and where possible to improve these capabilities.

In engineering the problems include the automatic generation of finite difference equations from partial differential equations and the Fourier stability analysis of these difference equations, the formulation of design rules for nuclear magnetic resonance coils, the free vibration analysis of beamlike structural lattices, the stress singularity at the vertex of a wedge shaped crack, and construction of nonsingular satellite theories. Problems involving the classification of geometries in general relativity, the evaluation of Feynman diagrams, the calculation of plasma modes and instabilities and computation of conductance distributions of percolation lattice cells occur in physics and chemistry. In the biosciences such prototypical problems require computation of generating functions for small RNA molecules, and the study of a multi-nephron kidney model. Mathematical problems include the determination of normal forms for differential equations, determination of the structure of Lie and other groups, polynomial factorization, evaluation of function space integrals, and Backlund transformation of soliton type equations.

The selection of a problem which will not overload the computational system and yet reward both the system designer and the scientist/engineer with new insight is not an easy task. Generally speaking the effective study of especially nonlinear problems depends on the ability to transform the problem from one form to another. Examples of such transformations include changes of dependent and independent variables in partial differential equations, series expansions of solutions, and transformation to a normal or canonical form. Often an expression must be tested to determine if it satisfies a condition. Many of these manipulations are too large and complex to be performed correctly by hand and will be increasingly performed using computers. The research goal is to extend and improve these capabilities.

8.4.7 Approximate Models for Control of Distributed Parameter Systems

Systems such as large space structures, adaptive optical devices, laser weapons and problems of aeroelasticity are best described by distributed parameter models. These models are infinite dimensional systems with dynamics governed by partial, functional or stochastic differential equations. The development of practical methods for identification, control and optimization of such systems requires that basic research be conducted in the area of approximation for these types of equations. An understanding of the effects (including sensor and actuator locations, performance, robustness, rates of convergence and practical implementation) of various discretization schemes on the control design is needed to assess potential benefits and limitations of each approach. In order to assure reliability of the control system, convergence results, error estimates and numerical stability of the approximation models must be analyzed. Research in the development of numerical models for identification, control and optimization of infinite dimensional systems may lead to practical algorithms for high performance

control of large flexible structures. Various finite element, finite difference and modal models should be analyzed. Although a particular finite element model may provide excellent parameter estimates, it may not be well suited for control design, and conversely certain spectral models lead to good control designs but are not practical models for identification. It is important that research in this area address such issues. Approximation of stochastic differential equations is an area of research that needs much more emphasis. Currently, there are very few good numerical schemes for approximating stochastic control systems.

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PROJECT FORECAST II



TECHNICAL AREA

PROJECT FORECAST II

INTRODUCTION

Project Forecast II was a comprehensive study to identify technologies with exceptional promise for improving the Air Force's warfighting capabilities for the future. A total of 39 Project Technologies (PTs) were identified for funding within the Science and Technology program, involving 6.1 basic and applied research, 6.2 exploratory development, and 6.3A advanced technology development. Of these, the 14 initiatives described within this section are considered to provide opportunities for 6.1 research investment based on current initiative implementation planning.

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9.1.1 PT-01 High Energy Density Propellants

The purpose of this initiative is to create propellants which can be expected to revolutionize operational rocket propulsion. The objective is to acquire propellants which have a heat release on order of magnitude greater than the best chemical propellant combination in use today, namely oxygen/hydrogen. This high energy content can be translated into enabling technology for a small, single stage to orbit rocket system (including horizontal take-off and landing) and some space missions (low earth orbit to geosynchronous earth orbit and return with large payload fractions). The potential exists for application to combined cycle engines and explosives depending on the nature of the resultant propellants.

The major thrust of this initiative is to accelerate research in selected areas of atomic and molecular chemistry for non-conventional propulsion. Of particular interest is the electronic structure of atoms of molecules where large amounts of conventional chemical energy can be made available if the electrons are situated in other than their "normal" ground states. Many "impossible" electronic states in "normal" environments have been shown to exist. Improved theoretical models predict the existence of more high energy species with lifetimes on the order of milliseconds and longer. The areas which appear to be most promising for propulsion applications are:

1. excited state compound where the energy can be stored and lifetime extended due to the formation of a chemical bond;
2. excited species where stabilization may be achieved through collective efforts and/or environmental effects;
3. high energy ground state molecules which are generally formed via excited state transformations.

9.1.2 PT-05 Space Power

OBJECTIVE: The objective of PT-5 is the development and demonstration of advanced non-nuclear and nuclear space power technologies capable of supplying 10-100's of kilowatts electric power (KW_e). The near-term objectives focus on technologies to generate 10-50 KW_e . PT-5 emphasizes those technologies leading to power system compactness and survivability, both natural and induced, to satisfy Forecast II system requirements.

APPROACH:

The near term approach is to:

Accelerate development of high efficiency solar cells and survivable solar array technology.

Accelerate development of high energy density rechargeable batteries based on sodium sulfur cell technology.

Investigate innovative space reactor concepts, their applications to Air Force missions, and develop appropriate spacecraft integration parameters.

The long term approach will:

Research advanced static and dynamic energy conversion processes.

Investigate critical life and design performance parameters of thermionic converters for nuclear reactor energy conversion.

Accelerate development of innovative thermal management concepts and materials.

Accelerate development of existing power processing and distribution component technology to levels needed for advanced Air Force missions.

PROGRAM PLANS:

6.3 Program: Two new major advanced development programs were funded by PE 63401F and implemented by AFWAL/P00. The first is the Survivable Concentrating Photovoltaic Array (SCOPA), a dual award effort to develop and demonstrate hardened, to both nuclear and laser threats, solar array technology based on concentrator cell technology using gallium arsenide solar cells. Down selection to one contractor occurs at the end of Phase I, "Component Development," in 4Q/FY 88. The second major new start is the High Energy Density Rechargeable Battery (HEDRB) program; this effort will design and develop a sodium sulfur (NaS) battery for use in geosynchronous applications. The HEDRB program will deliver six prototype NaS batteries.

6.2 Program (AFWAL): Initiate development of nominal 30 percent multi-bandgap solar cells. Continue development of sodium sulfur cell technology with goals of 35 watt-hours per pound for low-earth orbits. Continue development of thermal management technologies including heat pipe transport innovative radiators and thermal energy storage. Complete investigations of power processing solar array technology. Initiate assessments and trade-offs of photovoltaic-based power systems as compared to power systems based on solar thermal techniques. Initiate development of 2200 Kelvin static energy development for nuclear-based systems.

6.2 Program (AFAL): Continue exploratory development programs to develop and demonstrate thermal management and long term cryogenic space storage technologies. Efforts focus on technologies supporting Liquid Droplet Radiators, Direct Contact Heat Exchangers and Moving Belt Radiators.

6.1 Program: While no single task/project within AFOSR is specifically dedicated to PT-5, work conducted within the Aerospace Sciences and Physics Directorates and at the Frank J. Seiler Research Laboratory directly supports the fundamental science and technology base required for future space-based power systems including PF II Systems. This work falls into the following general categories of fundamental scientific investigations: plasma physics,

diagnostics for reacting flows, magneto-hydrodynamics, magnetic and dielectric materials, electrochemical power sources.

9.1.3 PT-10 Wafer Level Union of Devices

Wafer level union seeks to develop the technology to permit combining, on a single 3- to 8-inch sized sheet of material, all the microelectronic component technologies now possible only on separate, isolated, and mutually incompatible substrates.

Recent developments in gallium arsenide (GsAs) technology, such as the modulation-doped field-effect transistor from quantum-well research, support the needed technologies for combining substrate processes. Additionally, superlattice developments are also promising for integrating electro-optical and optical devices on chips of compound semiconductor materials. There are numerous processing methods ongoing that support the concept of wafer level union: laser processing, "dry" processing, as well as new inspection techniques such as acoustic microscopy. Thermal cooling of individual chips and wafers is another area that needs to be addressed. Recent work on combining the circuit elements of a Global Positioning Satellite (GPS) receiver on one chip demonstrates the concept of wafer level union. Technologies that need to be addressed are: optical interconnects to a wafer, integrated optical signal processor, microwave/millimeter wave phase shifter, single wafer digital/analog processor, and non-linear optical functions on a wafer.

9.1.4 PT-11 Photonics

Dramatic increases in Air Force system capabilities are achievable through the exploitation of photonic technology. Advances in materials research, wafer level integration, spectrally pure optical sources and detectors and optical fibers are needed before the improved capabilities can be realized.

Photonic research will involve examination of super lattice and quantum well materials, single mode optical fibers and spectrally pure laser diodes. Material research will include III-V compounds, photorefractives and fluoride glass. Some of the applications of this research include high information rate communications, high speed signal processing and optical computation.

Broad-based optical computing research will investigate processing algorithms, artificial intelligence and optical interconnects. The conversion to optics necessitates the development of a broad range of high-performance electro-optic components including directly modulated lasers, waveguide modulators, switches, optical amplifiers, and passive waveguide components. Multiaperture optics, multispectral sensing, optical pattern recognition and integrated optical processing will be significant areas of investigation in the development of all aspect sensors.

Development of efficient, low power, rugged materials for the generation, switching, and storage and detection of optical signals is required. Optic/electronic component integration will be a major area of investigation for information processing to take advantage of the speed and parallelism of optics. Optical device research will explore detector arrays, memory, logic arrays and spatial light modulators which could be the nucleus technology

for photonic information processing and computing systems. Algorithm research will focus on parallel algorithms, both analog and digital for optical processing.

Increases in communication bandwidth, signal processing speed, numerical computation speed, target detectability and resolution, and sensor sensitivity should all be achievable. Photonic systems should be much lighter in weight, occupy less volume, and be affordable.

9.1.5 PT-12 Full Spectrum, Ultra-Resolution Sensors

Projected Advances in electronics, information processing, materials, and computer technology offer the potential to make major advances in sensor technology. Surveillance, reconnaissance, target acquisition and tracking, and environmental monitoring from deep space, near-earth orbit, on aircraft or unmanned vehicles, and on the ground can be substantially advanced through the development of a wide range of sensors based on radar, laser/lidar, inertial navigation, IR and UV focal plane arrays, microwave, and millimeter wave concepts and designs.

This technology will focus on advances in both passive and active sensor capabilities. The principal passive thrust will continue to focus on major advances in IR technology (higher density detector arrays, semiconductor materials, superlattice geometries). In the active sensor area, the principal thrust will be in ultraband radar technologies (distributed monolithic microwave IC power amplifiers, wafer scale integration of optical, microwave, and digital functions, fiber optics transmission, and high speed digital and optical signal processors). Technology thrusts in environmental sensing will focus on spaceborne lidars (laser materials, diode arrays, non-linear crystals, stable optical coatings) and ultraviolet imaging sensors (higher spatial and spectral resolution).

9.1.6 PT-14 Survivable Communications Network

Various new network architectures, such as the packet radio, have to some degree made use of the adaptability of networking technologies to be more survivable. New signal processing technologies are enabling the development of sophisticated and adaptable transmission techniques. Distributed processing technologies are enabling the design of sophisticated network control functions that provide for the adaptive management of the scarce transmission resources that tie communications networks together. Networking and transmission techniques are being merged to produce new forms of networks such as the packet radio networks that offer several degrees of freedom which help to increase the survivability of communications.

The objective of this initiative is to create and eventually to demonstrate a highly survivable communications network. Applications for this technology will include strategic as well as tactical operations. Space applications are also considered part of this program. An integrated approach is anticipated in which the results of several existing programs currently developing applicable concepts will be drawn together with new approaches in the areas of adaptive networking, agile transmission techniques, and advanced terminal designs.

9.1.7 PT-15 Adaptive Control of Ultra-Large Arrays

The technology to which this project relates is designed to provide for the effective use of extremely large phased arrays such as distributed, sparse arrays in space and for arrays distributed over the skin of an aircraft. The objectives undertaken here include: improved sensor resolution; jammer cancellation; target tracking and identification; all aspect sensor and communications coverage from aircraft; enhanced sensor and communications systems capabilities; and the mitigation of atmospheric and ionospheric effects which degrade large antenna performance.

The following areas must be addressed and the results integrated in order to successfully complete the research:

1. stable sources and methods for cohering sources at many wave lengths apart;
2. precision location and navigation techniques to determine and track phased array element position;
3. integration with large structure mechanical control systems;
4. hardware for phase shifting, time delay, signal generation and processing in distributed arrays;
5. architectures and algorithms for self-organizing and self-cohering distributed phased arrays;
6. algorithms for effectively using the flexibility of large arrays to overcome jamming and environmental limitations.

9.1.8 PT-20 Ultra-Structured Materials

The general approach of this program is to establish major research efforts in ultra-structured materials definition, required processing techniques, and to correlate theoretical/experimental modelling. The long term goal is to exploit the potential for multi-functional materials; that is to combine structural features of molecular composites with electro/optical features.

From the 1960's (Forecast I) to the present, the understanding of the relationship between material microstructure and material properties has progressed to the point where manipulation of the microstructures is desirable. Fibrous composite materials and powdered metals are examples of the advances made by examining the microstructure of the material. Semiconductors have been grown one atomic layer at a time. The natural extension of these technologies is the tailoring of the materials at the molecular level so that the properties of the molecule are echoed at the macro level. Successful programs to date include observation of the theoretically predicted optical activity in superlattice photodetectors and successful fabrication of rugate filters and X-ray mirrors.

Ultra-structured compositions are emerging in all classes of materials: semiconductor/electronic, organic polymer, metallic/alloy, ceramic and opto-electronic. A key driving force pushing these developments to the

forefront today is the materials processing arena. New processes, process control and the processing/manufacturing science of very high quality Angstrom thick layers are essential for ultra-structured compositions. Because many of the compositions and structures are so new and because the electronic/lattice effects these structures produce are new, significant developments on the theoretical front will be occurring for a number of years.

9.1.9 PT-21 Cooling of Hot Structures

The objective is to achieve an effective method for cooling hot structures of exoatmospheric vehicles. New methods for prediction and analysis of heating leads, new concepts for control of high heat flux inputs, and new structural design criteria are actively being sought. The results obtained from this initiative are considered enabling to the full development of hypersonic vehicles.

Hypersonic vehicles have unique design and performance requirements and therefore unique heating requirements. No work in this area has been done since the early 1970s. Trajectories planned for forecasted hypersonic vehicles involve aero-maneuvers and flight times that lead to aeroheating loads of much greater intensity and duration than any previously encountered. The maneuverability, range, and cross range of hypersonic NASP-type exoatmospheric vehicles is dependent on the radius of the leading edge of the wing. The required radius can only be achieved through active cooling: transpiration, spray, heat pipes, etc.

9.1.10 PT-24 Hypersonic Aerothermodynamics

Efficient hypersonic flight offers the technical solution to problems of achieving reliable military access to space and will result in a means of accomplishing national security goals using military vehicles which immediately respond to threats. The particular flight path that a mission requires has a strong influence on payoff functions such as range, or the magnitude of orbital plan change. But maneuvers are only possible when the vehicle is stable through aerodynamic or electronic means and the control system has the required authority to pitch, roll, and yaw the vehicle. Advanced configuration research, synthesis, and integration are vital elements of performance. The technology will be developed on two fronts, one emphasizing new materials which are not affected by the high thermal environment and the other concentrating on aerodynamic methods to limit heat and maintain structural integrity. Hypersonic flight, whether in a cruise environment or as a transitory phenomena on return from orbit, will result in a means of accomplishing national security goals using military vehicles which respond to threats and show national resolve without delay.

The development of hypersonic aerothermodynamic technology usually includes the assumption that the force and moment coefficients are not strong functions of Mach number. This hypersonic approximation can be used to develop an evaluation criteria for reentry efficiency. High performance configurations are assumed to be slender, capable of flight at both high and low angles-of-attack using aerodynamic surfaces for control whenever the atmosphere is sufficiently dense. The state-of-the-art in nosetip cooling for hypervelocity vehicles has been most highly developed from maneuvering reentry

vehicle. It has been recognized that improved accuracy is achieved through higher flight velocity and consistent shape parameters. The performance of hypervelocity vehicles will be severely compromised until a stable nosetip shape can be maintained at all flight conditions. The development of optimum control devices for hypervelocity maneuvering and range extension must consider all the various devices and explore the aeromechanics efficiency which can be realized in their use. Canards are essentially destabilizing. They produce strong forces for rapid maneuvers, but usually require complex actuation logic with the associated problems of redundancy and safety. Strategic missiles employ various means of inducing moments, such as bent nose geometries, control flaps at the base, and a variable center of gravity. In recent years, aeromechanics emphasis has been on transonic flight and most of the high enthalpy facilities in the country were ignored. Now this technology must be re-acquired in order to proceed with confidence with new hypervelocity designs. Several flight test programs have been undertaken to demonstrate the capability of technology in preliminary stages of achieving hypersonic military flight. It is now practical to compute the velocity and streamline path of many points about the body to provide an insight into aerodynamic design.

9.1.11 PT-26 Brilliant Guidance

This Project Forecast II Initiative incorporates and integrates all relevant technologies required to develop a family of affordable weapons which autonomously acquire, track, and guide to a broad spectrum of air and surface targets, regardless of stand-off range, in any environment, and without post-launch communication. Also includes technologies necessary to ensure an optimum burst point for the warhead.

Recent advances in seeker technologies provide an opportunity in the next 10 years for the Air Force to develop a true autonomous lock-on-after-launch, adverse-weather capability for tactical weapons. IR detector and signal processing technologies, coupled with the development of acquisition and tracking algorithms, make possible an imaging seeker that will autonomously acquire and guide a tactical missile to a fixed designated aimpoint. Advances in laser radar (LADAR) technology will allow the design and fabrication of seekers to expand the target set to hardened targets and mobile high value targets. The LADAR could also provide targeting information for cuing of submunitions dispensing events from a smart submunition dispenser. The adverse-weather aspect will most likely be achieved with tactical sized synthetic aperture radars (SARs). Finally, the development of adverse-weather, multi-target autonomous tactical weapons will depend on the integration of data from multiple sensors in both the IR and radio frequency (RF) parts of the electromagnetic spectrum. This will require the application of artificial intelligence (AI) and the use of very high speed integrated circuits (VHSIC) to achieve the flexibility and robustness necessary in target acquisition and tracking.

There are basically four sensor technology options available for air-to-surface applications: passive imaging IR, active imaging IR or LADAR, SAR, and millimeter wave (MMW) radar. None of these options is best or worst in all of the desired characteristics of a tactical weapons seeker.

The technology challenge for Brilliant Guidance in an air-to-air application centers on the Identification, Friend or Foe (IFF) function. Recognizing the target as an aircraft is not enough. Now the algorithms must determine the exact aircraft type. LADARs have shown promise in being able to distinguish aircraft types by detecting characteristic vibrations. In addition, other aircraft signatures such as unique IR and RF emanations may be used for identification. The application of AI will undoubtedly be required to fuse all sensory information and make the final intercept.

Research will have to proceed in each of the technology areas discussed above to achieve the level of performance and the technology maturity to support Brilliant Guidance.

9.1.12 PT-36 Knowledge-Based Systems

The concepts that define the sub-field of Artificial Intelligence (AI) known as Knowledge-Based Systems (henceforth K-B Systems) have evolved over the past twenty years of AI research. To date, K-B Systems have been successfully applied to many diverse applications (e.g., medical diagnosis, molecular structural analysis, mineral exploration, computer hardware configuration, locomotive repair, communications switch repair, and many others). However, many questions must be answered before K-B Systems are employed in large, real-time military applications. Upward scalability, verification/validation of "correct" behavior, ability to reason with uncertain information, and real-time performance are but a few of the important technical issues that remain to be addressed before an "across-the-board" application of this technology can be considered.

9.1.13 PT-40 Virtual Man-Machine Interaction

The ultimate aim of research in virtual man-machine interaction technologies is to design, build, and evaluate interfaces which are intuitive and easy to use. This initiative will exploit the natural capabilities of the human in order to minimize cognitive demand and to create an efficient human-machine communications medium at sensory, perceptual, cognitive, and motor control levels.

Research on this project will be conducted at two levels. The first level is to establish and mature the basic materials and human sciences which will provide the technological foundations for new, interactive portrayal media. This activity will include establishment of an accessible data base for the design of virtual interfaces and the research needed to evolve more robust metrics for assessing the goodness of virtual world interface designs. The second level is to create and test components and software/algorithms with which to demonstrate virtual world interaction for ground-based and airborne virtual crew stations.

9.1.14 PT-41 Distributed Information Processing

The objective of PT-41 is to develop the technology to support dispersed and local clusters of heterogeneous processing resources interconnected by multi-media communications in such a way as to provide a reconfigurable information system that exhibits location independent access to both data and processes. Near term objectives will focus on prototype development

of heterogeneous cluster systems which are based upon local network connectivity and internettted via the DOD Internet. They will include both the distributed operating system and distributed database capability. Longer term goals include the implementations based upon Non-VonNeumann architectures and the capabilities evolving from the optical computing initiatives.

The near term approach will be to build upon current efforts and augment them with research and development activities in the areas of real time systems, fault tolerant mechanisms, distributed database management systems, and security. Longer term, the issues of dynamic reconfigurability based upon intelligent resources managers, very large data handling capabilities, processing clusters based upon mixtures of standard and non-standard architectures, optical processing and communications, and adaptive and self learning control mechanisms will receive the major attention.

During FY 88 - FY 92 the capabilities that are in prototype form today will be transitioned into fielded systems. This will include the capabilities to operate multi cluster distributed configurations of different computers across multiple media long distance communications. Overlaid on this backbone will be distributed database management systems and support tools to allow the efficient implementation of distributed applications. Continued R&D will be pursued to incorporate special architectures such as parallel processors, database machines, connection machines, etc., as they become available. New strategies will be developed for dynamic control of the resources based upon the incorporation of intelligent algorithms that include the concepts of best efforts decision making and real time deadline scheduling. The maturity of these techniques will allow the realization of dynamic reconfigurability which is the basis for survivability in distributed systems. As the products from the Photonics initiative in both the optical communications and optical processing area begin to evolve, the necessary mechanisms to incorporate them into a distributed systems environment will be developed.

Efforts during FY 93 - FY 94 will concentrate upon very high performance clusters of processing elements interconnected by very wide bandwidth (>100mbyte) links and incorporating optical processors and very large database handling capability. Systems will automatically load balance and reconfigure based upon self learning algorithms, and include configurations of several dozen nodes. During this time period the technology will be maturing which will allow the systems to operate in a multi level secure environment.

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